



PULMONARY CIRCULATION  
AND  
RESPIRATORY FUNCTION

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A  
SYMPOSIUM  
HOLD AT  
QUEEN'S COLLEGE



DUNDEE

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UNIVERSITY OF ST ANDREWS  
1956

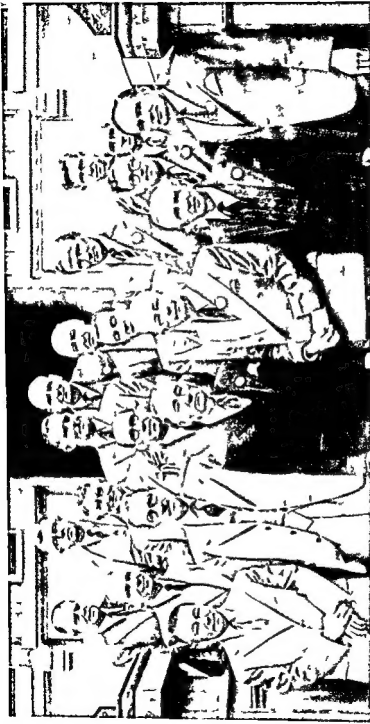












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## INTRODUCTION

When it became known that Dr Averill Liebow Professor of Pathology of Yale University was to be the Praelector in Pathology at the University of St Andrews for 1955 it was felt to be a unique opportunity to bring together those in Britain who had a special interest in the lungs. The Faculty of Medicine conscious of the sad walls that bound the specialties decided to call together for a symposium workers within the pulmonary field be they physiologists or physicians surgeons or pathologists. The Court of the University of St Andrews agreed to support the scheme and so there met in September 1955 at Queen's College Dundee the group whose names are listed elsewhere.

As a jejune youth said recently By good luck Providence was on our side and it was generally agreed that the stimulating air of the Firth of Tay produced a genial indeed a happy and productive conference. Many have already expressed the gratitude due to those who offered fresh views fertile ideas and friendly discussion and to these we would add the Thomson Fries of Dundee who have produced this volume of proceedings.

*The Editors*



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15th SEPTEMBER

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# Pulmonary Vasomotor Nerve Activity And Its Possible Functional Significance

I DE BURGH DALY (Institute of Animal Physiology Babraham Cambridge)

Whether pulmonary vascular resistance is normally modified by extrinsic vasomotor nerves is still a controversial issue (1 2) In discussing this problem two kinds of evidence will be considered here —

- (a) The results of animal experiments in which pulmonary ventilation and circulation are controlled artificially and
- (b) P V R (pulmonary vascular resistance) measurements obtained on human subjects

Experiments on perfused lungs of animals (3) chiefly dogs were originally designed to meet the difficulty that large passive changes in pulmonary flow pressure and resistance may obscure or vitiate the demonstration of active vasomotor nerve responses Passive changes in resistance can occur secondarily to alterations in lung blood flow or as the result of bronchoconstriction or any change in ventilation that alters the intrapulmonary pressure Because of the communications through the bronchial system (4) of vessels between the systemic and pulmonary circuits other errors may arise for the effects of a change in resistance of the bronchial arteries and their communicating vessels due to bronchial vasomotor activity (5) or of a change in systemic pressure (6) can be transmitted to the lesser circuit

To eliminate such effects innervated isolated lung preparations (7) were perfused at constant volume inflow or at a constant head of pressure with free outflow of blood from the left auricle Bronchomotor effects which are particularly suspect (8 9) were regarded as absent during nerve stimulation tests if the tidal air or ventilation overflow remained constant under controlled negative or positive pressure ventilation respectively these methods record both changes in lung viscance and elastance but do not distinguish between them In other experiments on whole animals with a widely opened thorax the systemic vessels were also perfused at constant blood volume inflow (10) To demonstrate the existence of pulmonary vasomotor nerves both the sympathetic and parasympathetic trunks supplying the lungs have been stimulated Pulmonary vascular responses to such stimulation are regarded as proven only if they can be demonstrated at zero systemic blood pressure and in

the absence of any bronchomotor response (Fig 1)

To eliminate bronchoconstriction (broncho dilation rarely occurred) it is usually necessary to atropinize the animal This may account for the fact that the predominant motor response is vasoconstrictor since the vasodilator responses which have been obtained from time to time are atropine sensitive

The net result of these experiments is to show that both vasoconstrictor and vasodilator fibres are present in the autonomic nerve supply of the lungs and from pharmacological evidence it appears that most of the vasoconstrictor fibres are sympathetic in origin with cell stations in the stellate and middle cervical ganglia and with post ganglionic neurones which are adrenergic So far as they go these experiments seem conclusive But in order to effect all the controls necessary to demonstrate unequivocally active pulmonary vasomotor responses the conditions of the experiment become highly artificial and may possibly lead to a modification of normal responses This is suggested by the observation that an initial sympathetic nerve stimulus or adrenaline injection sometimes reduces the P V R whereas subsequent similar procedures raise the P V R Is it possible that perfusion leads to sensitisation of the vasoconstrictor or to paralysis of the vasodilator neuromuscular apparatus? The P V R of perfused lungs is much greater than normal which may be predominantly due to constriction of vessels other than those responsive to nerve stimulation with the result that the responses are greater than normal The results may therefore represent the physiological potentiality of the lungs rather than the normal working mechanism

The demonstration of an independent control of the lung vessels in human subjects requires that in some way passive effects as outlined above be eliminated Since a change in cardiac output per se alters the P V R there is no justification for attributing recorded changes in P V R ( $\Delta p/\text{flow}$ ) to a vasomotor nerve control unless it can be unequivocally established that there are no accompanying changes in cardiac output and efficiency (such as to alter the left auricle pressure) An increased bronchial circulation development in pathological lungs so beautifully demonstrated in detail by Doctor

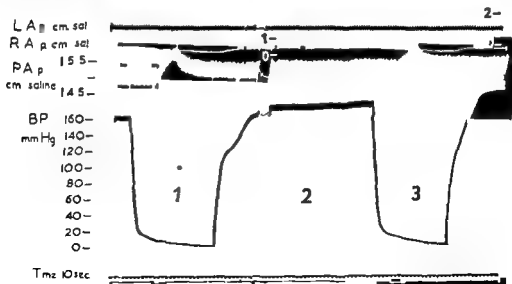
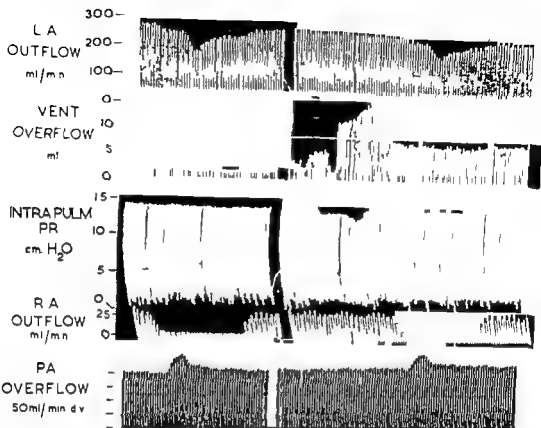
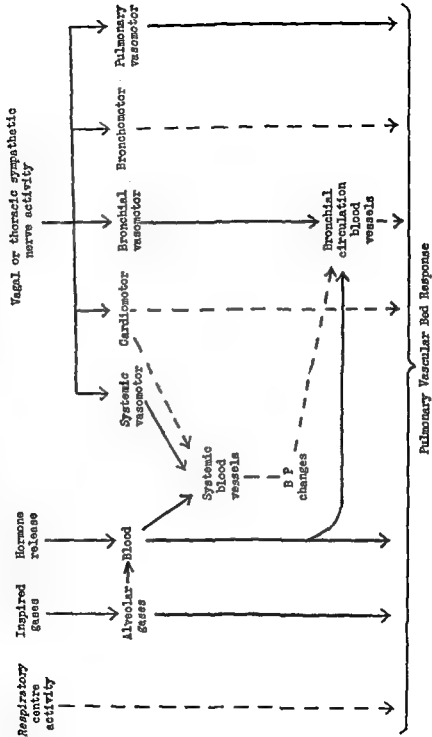


Fig 1-5 planat on page 4

ACTIVE (—) AND PASSIVE (---)

EFFECTS ON THE PULMONARY VASCULAR BED







caused little change in the pulmonary arterial pressure. They considered that this decrease of pulmonary vascular resistance during exercise could only be due to the widening of the vascular channels or to the opening of new channels. Courmand combined his studies of pulmonary arterial pressures after pneumonectomy with those of Riley and concluded that there was no significant increase of pulmonary arterial pressure until the rate of blood flow through the lungs exceeded  $10\text{ l/min/m}^2$ .

Dexter and ourselves have not been able to confirm this in subsequent studies. Our observations in normal subjects suggested that the pulmonary vascular resistance remains fairly constant and that there is a proportionate increase of pulmonary arterial pressure as the flow rises. These findings are more in accord with the older concept that on exercise the pulmonary circulation transmits the blood pumped by the right ventricle almost passively.

The measurement of pressures in the left auricle and pulmonary vein in the intact human presents great technical difficulties. The passage of the catheter through an atrial septal defect or an unclosed foramen ovale gives figures in the region of  $5.8\text{ mm Hg}$  but the possibility of abnormal haemodynamics under these conditions must be borne in mind. The pulmonary capillary pressure is even more difficult to determine. Hellems and his colleagues impacted the catheter in one of the lesser radicles of the pulmonary artery and measured the pressure cautiously in their conclusions they felt that as the blood withdrawn was fully oxygenated there was probably full communication between the impacted catheter and the capillary bed. This and the fact that the pressures were a few mm higher than in the left atrium suggested that this was a reasonable approximation to pulmonary capillary pressure. However it is probable that the blood flow through the whole of the lung segment concerned is brought to a standstill by this procedure and that there is little if any collateral anastomosis with other segments. Under these conditions the vascular bed is now being employed as an imperfect and unusual extension to the catheter connecting it with the pulmonary veins. The static circulation of this segment can thus be used to aspirate pulmonary venous blood or to record a crude transpulmonary venous pressure.

Allison's remarkable technique of needling the left auricle from the air passages has shown very similar pressure levels and variation as recorded directly and through the impacted catheter (Epps and Adler). Yet these studies

were in patients with considerably raised pressures and animal experiments still cast doubt on complete concordance when the pressures are normal.

Experiments with animal and perfused human lungs have shown the passage of small spheres far larger than could pass any capillary bed. There is still considerable debate about the significance of such experiments but the general consensus of opinion is that although there are probably arteriovenous shunts they are more potential than functional in the healthy normal subject. Indeed significant short circuiting of the alveolar capillaries with their negligible resistance would appear both unlikely and against the interests of the organism.

The occurrence of precapillary anastomoses between bronchial arteries and the pulmonary circulation has also been studied a great deal recently. Animal experiments again suggest that although these may exist in the normal animal or human subject they are again more potential than functional. In many diseases this anastomosis can become very considerable.

Finally we come to the great problem of vasomotricity of the pulmonary vascular bed. On the whole it remains unsolved. Changes of pulmonary resistance in response to various stimuli such as anoxia, adrenaline, hypotensive drugs etc. have been shown in many animal and some human experiments. Yet these results are so frequently different with varying techniques and circumstances and between different species of animals that one begins to wonder whether they are an important significant factor in circulatory function in health. Admittedly nerve endings and receptor organs have been shown in the pulmonary artery and veins and nervous impulses varying with pressure in these vessels have been recorded. Joseph Barcroft felt that their very presence must have some significance yet even his amazing intellect could see no further. I would make a most tentative suggestion that although there is undoubtedly some vasomotricity of the pulmonary vessels this may be an example of vestigial function which is no longer of importance. Extreme and even differential changes in blood flow of the gill arches would appear to be a reasonable necessity in the early stages of evolution but marked changes in the resistance of the pulmonary circulation in response to various stimuli may be no longer necessary and even undesirable in healthy mammalian life. That almost vestigial structure the coccyx which still contributes as a very minor and almost unwanted attendant in fish defaecation used to

wag the tail. Is it possible that vestigial vasomotricity of the pulmonary bed has wagged the dog and given us this discouraging array of contradictory protocols?

### **Pulmonary Circulation in Disease**

The pulmonary circulation is as variable in its response to disease as it is to experimental procedures. The outstanding problem is the development of increased resistance to flow and of pulmonary hypertension in various diseases.

In mitral stenosis there is a considerable increase in pressure behind the mitral valve and at first the pressure gradient in the lung vessel behind the obstruction remains the same; all pressures rising by roughly the same amount. Many such patients are still capable of almost normal activity and are in constant danger of acute pulmonary oedema. This is presumed to be due to the capability of these patients to increase their cardiac output but only at the price of high pressures behind the mitral valve. A further possible contribution may be an increase of rapidly circulating blood volume owing to the diversion of blood from the placenta and resting area. In the presence of a normal resting cardiac output there is little vasoconstriction in these areas at rest and therefore a considerable volume of blood can be diverted from them on exercise.

In time varying degrees of further pulmonary hypertension develop in most patients with mitral stenosis; the considerably increased gradient across the lung being presumably due to increased pulmonary arteriolar resistance. The degree of increase and the rate at which it occurs is at present quite unpredictable. The pulmonary artery pressure may rise to very great heights in a young child in a few years, whereas another patient who has tight mitral stenosis and considerably raised transpulmonary pressures may not develop marked pulmonary arteriolar resistance for many years if at all.

The fact that patients with an increased pulmonary resistance although usually more disabled in everyday life rarely develop fulminating pulmonary oedema is held by some to suggest that this increased arteriolar resistance is protecting the capillaries from sudden and dangerous rises in pressure. Yet the only possible result of this increased precapillary impedance is that the right ventricle does not fail as far greater work for that ventricle and higher pressures in the pulmonary artery to maintain the blood flow. We do not hear of systemic hypertension having any direct haemodynamic effect on the capillary bed even when there is associated

congestive failure. The systemic and pulmonary capillary pressures are influenced by the venous pressure which is in turn influenced by atrial pressures. If the mitral valve impedance to outflow from the lungs remains constant or increases there would appear to be only one favourable circumstance in which the back pressure in the lung vessels could be reduced and that is with a reduction in blood flow. It is well known that the cardiac output is usually considerably decreased in these patients and that it is often unchanged on exercise. This is almost certainly due to the increased mitral valve obstruction. The stroke volume at rest is small and any increase in pulse rate unlike conditions in the normal subject is only at the cost of even more impaired ventricular filling with reduction in stroke volume and little or no resultant increase in total flow. Thus these patients are no longer capable of producing sudden increases of flow and a surging of blood against the mitral valve. It may be suggested that the considerably increased pulmonary arteriolar resistance will of itself cause a reduction of right ventricular output and thus guard the impeded lung circulation from further rise of venous and capillary pressure. Yet this is not the case either with the right or left ventricle working against increased resistance until after failure supervenes. Another possible cause of relief from severe rises in transpulmonary pressures could be a favourable alteration in the pressure-volume characteristics of the left atrium and pulmonary veins. It is fortunate but nevertheless fortuitous that these more disabled patients are less prone to acute pulmonary oedema. The word protection is in any case undesirable as it is difficult to believe that a species evolves purposeful protective mechanisms against such severe chronic crippling diseases in an unfortunate minority.

Returning to the enigma of pulmonary hypertension in disease we still do not know why some cases with increased pulmonary flow such as occurs in patients with a patent ductus arteriosus or intracardiac defect develop severe and killing pulmonary hypertension and yet others who are in no way different as far as we can tell do not develop increased pulmonary vascular resistance. How much this rise in pressure is due to morphological changes in the vessels or due to increased vaso-motor tone is not yet clear. Pressure and even histological studies after the correction of obstruction or increased flow although of great clinical importance will not entirely solve this problem. The genesis of hypertension in the pulmonary vascular bed remains as great a mystery as that of systemic hypertension. We have far to go

# Some Applications Of Basic Knowledge Of The Collateral Circulation Of The Lung

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The establishment of a pulmonary collateral circulation provides a means for redirecting the flow of blood through the lungs that may be useful in therapy.

Congenital transposition of the great vessels presents circulatory problems that are at least partly subject to surgical revision. Ligation of all pulmonary veins in the dog is followed by a large collateral circulation that drains fully oxygenated blood from the operated lung into the azygos and other systemic veins and thus to the right side of the heart (1-4). The volume of blood flow through this system reaches approximately one sixth of what would be expected under similar conditions of anesthesia had the lung been intact (4). The ready establishment of these collaterals and the considerable magnitude of the flow obtained in a relatively short interval of time (3-5 months) suggests that ligation of the pulmonary vein might be one approach to securing a left to right shunt of highly oxygenated blood that ordinarily would circulate through the left side of the heart in instances of transposition of the great vessels. This shunt would aid in the refreshment of the desaturated blood that pursues a course through the right sided systemic vascular circuit in these patients. One advantage of the suggested procedure is that the shunt carries the blood inevitably from left to right whereas the course of the blood after the creation of a defect in the inter atrial septum is unpredictable. One possible difficulty is that the venous pressure might rise to high levels when the pulmonary veins are occluded under the circumstance of the markedly elevated pulmonary arterial pressure that usually prevails in these patients (5). A method of circumventing this problem would be to ligate both the pulmonary arteries and veins. This procedure has proved feasible in the dog without infarction of the lung or abolition of its respiratory function. The blood flow through such a lung supplied entirely from the aorta and draining into the right heart only slowly rises to levels of 300 to 500 cc (occasionally more) in three to six months time. Were this procedure to be practiced in transposition the ultimate effect would be simply the introduction of the lung into the systemic vascular circuit (Fig 1).

The enormous blood supply to the lung from the aorta via bronchial arteries that is induced after interruption of the pulmonary arterial inflow (7-9) may be applied as collateral blood supply to the heart by cardiopneumonopexy (10). After this procedure three types of anastomoses have been observed—1—Transpleural Anastomoses—these may reach a diameter in excess of 1 mm and join branches of the coronary and bronchial arteries (Fig 2). 2—Retrocardiac Anastomoses—that connect enlarged branches of the left circumflex coronary artery usually the left atrial with bronchial vessels along the major bronchi or within the mediastinum. 3—Inter coronary Anastomoses. Studies of the hemodynamics by means of angiography and catheterization have revealed that after approximately one year some 5% of inflow into the coronary sinus is received from the collateral vessels. The direction and volume of flow are measured by introducing Evans blue dye at a point into the aorta just above the ostia of the collateral vessels and simultaneously measuring the dye concentration curves at 4 points. In the femoral arteries in the coronary sinus in the right atrium in the carotid artery (proximal to the point of introduction of the dye).

It may be suggested that simple cardiopneumonopexy without ligation of the pulmonary artery would be highly desirable in most instances of transposition of the great vessels. In these individuals the pulmonary arterial pressure usually exceeds that in the systemic arteries such as the coronary arteries and the latter also contain desaturated blood.

It is obvious that only the last of these various procedures is without cost in terms of pulmonary function. The cost may nevertheless be worth the possible benefit to be obtained.

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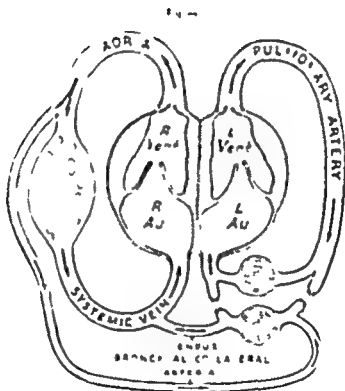
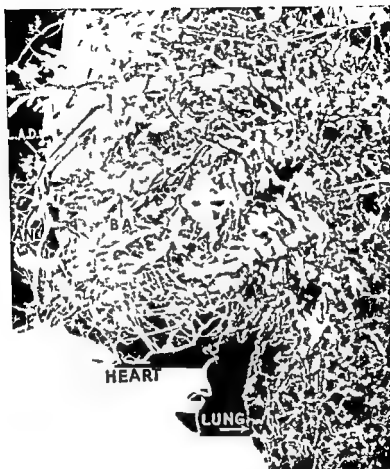


Figure 2



The specimen of left rodent lung after ligation of the pulmonary artery performed 10 months previously is shown from the lateral aspect. Most of the specimen is composed of white and yellowish (LAD) and greatly enlarged bronchial trees. One of the left (BA) indicated by an arrow in the photograph is it spirals about the bronchus. A dense network of iron chloride can be seen in the lung in the lower margin of the photograph at the right.

# Observations On Control Mechanisms In The Right Ventricle In Health And Disease

SIR RUSSELL BROCK (Guy's Hospital London, S E 1)

Others will no doubt deal with details of the circulation within the lungs. I propose to present some of my observations and experiences in connection with the more central control of the pulmonary circulation as exemplified by the action of the outflow tract of the right ventricle in both health and disease. In particular I wish to record observations and deductions made from my experience in some 250 direct operations for pulmonary stenosis.

## The Normal Right Ventricular Outflow

It is first necessary to consider briefly the construction of the normal right ventricular outflow tract from its funnel shape it is often called the infundibulum. When examined after removal of the atria and the superficial investing layer of circular muscle fibres it stands out as a separate part of the right ventricle in a manner suggesting it has a separate function.

The key to this lies in its development. In the fish and the amphibian heart the bulbus cordis exists as a separate part or chamber which is not seen in the mammalian heart except during its development. It then loses its identity by becoming absorbed into the musculature of the infundibulum.

Keith in 1904 suggested that this separate anatomy and morphology of the infundibulum indicates a separate function from the rest of the right ventricle. He pointed out that in the gill breathing vertebrates the bulbus receives the load of the ventricle and forces it onwards into the aorta leading to the gills and act as a mechanism controlling the flow and the efficiency of the valves. He suggests that in man the competence of the pulmonary valves depends on the tonus and action of the infundibular muscle and quotes experiments of Gibson (1898) to support this.

These experiments have been repeated and confirm the part the ventricle plays. It is pointed out that the right ventricle does not contract as a whole but a progressive wave of contraction passes up the infundibulum this can be observed with the naked eye when carefully looked for but is perfectly demonstrated in a slow motion film such as that of Prinzmetal.

In addition it is likely that variations in tonus of the outflow tract are of importance in the function of the right ventricle. Variations in

tonus are probably the cause of the attacks of severe cyanosis and loss of consciousness seen in Fallot's tetralogy. It is otherwise difficult to account for them. If the tonus of the infundibular muscle increases the pulmonary stenosis is made worse and less blood goes to the lungs at the same time more venous blood is shunted into the aorta. As cyanosis increases and the condition deteriorates the coronary circulation begins to fail and an escape mechanism functions otherwise death must follow.

Variations in tonus of the infundibulum have been shown by electromanometric tracings before and at operation and will be demonstrated.

Somewhat allied to this question of varying tonus in the infundibulum is another phenomenon seen in some cases of pulmonary valve stenosis with an intact septum. After pulmonary valvotomy in some cases it can be demonstrated that a secondary stenosis develops immediately in the infundibulum. This is due to relief of the distension present behind the valve stenosis as soon as the valve obstruction is relieved the walls of the infundibulum fall together.

This observation is fully illustrated and its significance discussed. It is doubtless the cause of many of the so-called failures after trans ventricular valvotomy in which the pressure in the right ventricle remains too high. The suggestion that these failures can be prevented by routine transarterial valvotomy under direct vision is probably not correct. Additional infundibular resection may be effective but no always. Perhaps shrinkage of the gross hypertrophied muscle may set up a progressive

benign circle. These cases are a warning not to delay relief of pulmonary valve stenosis until gross muscle hypertrophy has occurred so as to make the ventricle muscle bound.

Observations will also be presented on the secondary effects on the pulmonary circulation of relief of the stenosis in Fallot's tetralogy by direct operations. It will be shown that there is no real truth in the criticism that a condition of Eisenmenger's complex will be caused. Reports will be given of catheter studies on the pulmonary circulation after direct operations. Pulmonary flow is not necessarily related to pressure and examples will be given in which the pulmonary artery pressure remains below normal after very successful operation and yet the clinical and

functional result is perfect cyanosis and disability are totally relieved and the pulmonary blood flow is seen to be normal. In other words the important factor is the pulmonary resistance which seems to remain low. It may be that in later years after a long follow up we may observe an increase in pulmonary resistance and

the later development of secondary pulmonary hypertension even with reversed flow and recurrence of cyanosis but so far no example of this has been seen. The successful development of closure of the ventricular septal defect which will certainly be achieved should in any case prevent the onset of such changes.

## Cor Pulmonale In Coal Miners

J. GOUGH (Department of Pathology Welsh National School of Medicine Cardiff)

At the beginning of the present century the expectation of life of British coal miners was good and apart from accidents coal mining was regarded as a healthy occupation. There has however been a change and when compared with other occupations the miner has lost his former advantage. This loss has occurred progressively as shown by an analysis of the death rates at the census periods 1910-12, 1921-23 and 1930-32. There was no census 1940-41 but the preliminary analysis\* relating to the census of 1951 shows that the hewers and getters of coal in England and Wales now have a poor expectation of life compared with all occupied and retired men aged 20-64: the standard mortality ratio (154) being higher than for any of the other occupations analysed. Included in the causes of the high death rate are myocardial degeneration (186 SMR). These are additional to deaths returned as due to rheumatic and coronary artery disease. These myocardial cases undoubtedly include pulmonary heart disease which in miners in Wales is commonly due to massive pneumoconiosis (Gough 1947; Wells 1954). In 1000 consecutive autopsies on coal workers at the Welsh National School of Medicine in the period 1947-50 Dr W. R. L. James found that 218 had died of cor pulmonale. In most of these cases the heart disease resulted from massive pneumoconiosis. The latter is associated with striking changes in the blood vessels: severe obliterative arteritis occurring as a result of the extension of granulation tissue including dust-bearing cells through the walls of the vessel. Associated thrombosis may propagate from areas of massive fibrosis into larger branches of the pulmonary arteries. A considerable part of the periphery of the pulmonary arterial tree thus becomes obliterated. Commonly the main branches of the pulmonary arteries running

towards the areas of massive fibrosis are of normal calibre for a few inches and then end abruptly having given off only a few small branches. These changes have been described in detail by Wells (1955) working in the Medical School at Cardiff. He also demonstrated the arterial obstruction radiologically at autopsy using radio opaque material injected into the pulmonary circulation.

Lavigne (1951) concludes that the cardiac and respiratory causes of death in Belgian coal miners are the same as those in Wales. Massive pneumoconiosis produces striking hypertrophy of the right ventricle. This form of pulmonary heart disease has been investigated during life by Thomas (1948) who found radiological evidence of enlargement of the right ventricular outflow tract. He (1951) also examined hearts from autopsies and showed that the wall of the right ventricle was greatly enlarged compared with that of the left. He found that the cardiac failure is of low output type (1953).

Paper mounted sections of lung (Gough and Wentworth technique) have been used to study the coal miners' lungs. They show clearly the character and extent of the pneumoconiosis and of the accompanying emphysema. The method has also been applied to ordinary cases of chronic bronchitis and of status asthmaticus. It was unexpectedly found that spasmodic asthma even of very many years duration may not cause cor pulmonale. The lungs in status asthmaticus showed over distension but did not show bullous emphysema and thus differed from lungs with chronic bronchitis. The reason why the latter causes pulmonary hypertension is not certain but there are often associated changes in the bronchial arteries which may be the cause (Cudkiewicz & Armstrong 1953).



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## DISCUSSION

### Professor McMICHAEL

Professor DILL has indicated the complexity of physiological analysis of the pulmonary circulation in the dog's lung. Most of us will agree that under his experimental condition he has established that the lung vessel has a motor nervous system.

There is a great deal of evidence to suggest that the lung arterioles have little tone. There is a great deal of evidence to suggest that the flow without much pressure change. This principle explains the success of Brock operation in spite of absence of pressure alteration. Lee and Dubois (1955) have recently shown that the uptake of oxygen in the lung has a pulsatile character — a resting that the alveolar capillary blood with the heart beat. During the systolic reaction which follows a local experiment the lung vessel has no response in normal subjects. Considerable fluctuations of pulmonary arterial pressure in animals may occur with corresponding reaction in the motion of attitude of the pleural membrane during a cause a very considerable drop in pulmonary arterial pressure beyond anything explainable on pressure consequence of output changes. But in the mean circulation time from right atrium to the air and multi-lobed disc output estimation we can calculate a central cardiac-pulmonary blood volume. With normal motor control this volume diminishes by about 250 cc on standing upright (Gilmore et al 1951). Methionum appears to inhibit this constriction of the lungs. The observation of open and closing of lung capillary in the last minute I think be an artifact like some minor observation on the glomerular capillary. Such a phenomenon would imply impairment of efficiency unless the bronchioles are simultaneously and the same area behaviour in an identical fashion. Of pulmonary arteriole vasoconstriction under pathological conditions there is no possible doubt. Donald has indicated the stages in its development in mitral stenosis. He is in a better position to extreme the pulmonary artery pressure even exceeding the systemic. This is preceded by a stage at which even mild exercise seems to induce pulmonary vasoconstriction. McCallum, Goodwin, Steiner and Lowe have shown anatomically that in mitral stenosis across narrowing of the arteries occurs particularly in the lower part of the lung. This localised distribution of a local narrow may inter-

fere with the validity or at least the repeatability of so-called pulmonary capillary pressure readings.

Intensity of pulmonary capillary pressures over 30 mm Hg must be due to the fact that death or oedema is likely above this level. If her readings must be as without oedema unless capillary filtration different from our usual conception of it.

The pulmonary hypertension of emphysema is nothing like so intense as that seen in mitral stenosis. It is of an episodic character related to attack of bronchitis with exacerbations of anoxia and cyanosis (Mounsey et al 1953). The mechanism here is obscure. A few years ago we thought that a local reaction of the pulmonary vessels to anoxia was the answer but much doubt has been cast on this validity of the explanation both by clinical (Fishman et al 1955) and animal experimental observation (Nahata et al 1954). It is quite likely that the reaction is a complete response to asphyxia in oxygen, mainly humoral and nervous mechanisms. The functional and variable pulmonary hypertension of ordinary bronchitis emphysema differs from the aortic obstructive type demonstrated by Goetz in South Wales.

The lung vessel as a whole probably contain at any one moment 600-800 ml of blood. Of this only about 60 ml is undergoing active respiratory gas exchange in the alveoli (Roughton 1945). The anatomical capacity of the alveolar capillaries must be a very large total volume in the lungs—possibly 300 ml. Dr Hugh Jones has suggested that this may mean that under resting conditions active gas exchange is completed in the proximal end of the capillary and that the rest is in reserve for higher demands. We realise. When we apply the method of estimation of pulmonary blood volume to cardiac patients the results are most interesting. In left ventricular failure the constriction of the lungs is associated with an increase in pulmonary blood volume. In mitral stenosis no increase in lung blood content is demonstrable in spite of the increased alveolar pressures. It appears that the lung vessel as a whole has lost the elastic expansion properties—in short the vessels are indurated as pathologists have long described them.

To sum up some points in my ancient scientific creed—1—I believe the lungs vessels have an autonomous function which comes into action and is demonstrated only under special circumstances. This is nothing unusual and has its counterpart in for example the problem of innervation of the plain muscle of the stomach.

—I do not think the volume of blood flow in



Cyres Lecture 1st year offered an explanation for the phenomenon (Hayward 1955) describing the development of physical barrier in the interstitial tissue between the pulmonary capillaries and alveoli so that at these high left atrial pressures plasma may filter through the capillaries but is held in the interstitial space the lungs becoming very rigid in the process the interstitial fluid is practically removed by the lymphatics and may be largely responsible for the radiological appearances which have been previously attributed to pulmonary venous congestion

There is on other point I would like to mention in relation to mitral stenosis namely our inability to demonstrate any functional abnormality between pulmonary and bronchial vein. I have tried to do this in two ways — (1) By taking samples from the superior vena cava above and below the junction of the azygos vein — I should have been able to show an appreciable difference between the two if oxygenated blood in any amount is entering the vena through these anastomotic channels in fact however samples from the two veins have shown identical results. (2) By injecting indigo into a peripheral pulmonary artery through either the edge of position excellent definition of the arterial and venous system of the segment containing the stenosis but out of a dozen such experiments I was only once able to demonstrate filling of a bronchial vein through the stenosis.

Turning now to Sir Russell Brock's remarks concerning the relationship about the regulating function of the infundibulum on the pulmonary blood flow in reflex and myogenic I have a few observations to make which lend additional evidence to the view at least in respect of the situation in mitral stenosis. I have injected four cases of mitral stenosis with a venous attack of myogenic of consciousness occurring in two and in the other two instances without loss of consciousness in the other two. In the first case the murmur and thrill either disappeared following the recovery from the attack or the arterial oxygen saturation dropped noticeably usually to 70% in one of them. In the other two the arterial blood pressure remained normal and the systolic murmur felt that a drop in the arterial pressure was responsible for the decrease in right to left shunt. In the most extreme example with a normal arterial oxygen saturation and the arterial blood pressure from 100 to 150 mm Hg by means of the technique but this made no difference whatever to the physiological situation.

The second characteristic in the form of the pulmonary arterial pressure pulse in mitral stenosis. In some cases the mitral regurgitation is associated with eccentric systole is briefly halted and succeeded by a systolic trough. It is usually thought that the phenomenon which at one time is thought to be an artefact could well be the result of a sudden shutting off of the pulmonary arterial flow halfway through the cycle caused by functional closure of the infundibulum.

Since much has been said about pulmonary hypertension I thought it would be well to show a table giving the actual frequency with which an extreme pulmonary vascular resistance (10-30 units or 800-1400 dynes/cm<sup>2</sup>/sec/cm<sup>2</sup>) develops in the chief condition in which such a reaction may occur. In considering the frequency of this reaction one must be careful to include only cases of critical severity. For example both patent ductus and entricular septal defect must be closed on the first day before an extreme pulmonary vascular resistance has a chance of

developing. In these and in cases of atrial septal defect the communication has been considered critical if it has resulted in a pulmonary blood flow at least three times the systemic flow or of course in a raised pulmonary vascular resistance. Mitral stenosis has been considered critical if the valve orifice was around 1 x 0.5 cm. The degree of mitral incompetence is more difficult to assess but cases have been included as critical if they gave rise to certain symptoms and clinical features which would have demanded surgical relief had a suitable operation been available. Chronic pulmonary disease was diagnosed on clinical ground and all cases with an arterial oxygen saturation below 90% at rest have been included provided the patient was free from acute respiratory infection or asthma at the time. The table shows the remarkable differences in the frequency of an extreme pulmonary vascular resistance (average 17 units) in the six groups ranging from more than 50% in severe mitral incompetence to 5% in critical ventricular septal defect. Cases of Eisenmenger's complex atrial septal defect with reverse flow and patent ductus with reverse shunt have of course been included. Left ventricular failure has been omitted from the table only because we haveatherotomized too few of these cases to form any idea of the frequency of the reaction. The number of cases of primary pulmonary hypertension has been given for comparison. The total number of all these severe pulmonary hypertensive cases represents 1.3 per cent of about 10,000 cases of cardiovascular disease examined personally by the author over the past seven or eight years.

Just what determines the wide variation in the reaction of these different types of cases is unknown. The first three appear to be reactive to an initial increase of flow, mitral stenosis and incompetence to rise of left atrial and pulmonary venous pressure and cor pulmonale to anaemia. An obvious underlying principle that might underlie all these cases is the development of active pulmonary vasoconstriction in response to a rise in pulmonary arterial pressure however produced—a vicious circle mechanism—but this is pure speculation. No theory purporting to explain active pulmonary hypertension can be valid however unless it also explains the variable behaviour shown in the table. An inborn tendency to react in this way has been postulated.

Finally I would like to show a slide illustrating a new technique for measuring the amount of function in a motor tone in any case of pulmonary hypertension. What this can be separated from any anatomical block in the circulation. If approximately 1 mgm of acetylcholine is injected into the pulmonary artery the proximal lumen of a double barrelled catheter a continuous record of the pulmonary artery pressure pulse can be obtained by means of the second barrel. The dose of acetylcholine must be such that it is totally destroyed by the time it passes through the pulmonary artery bed and from trial and error 1 to 1.5 mgm seem to be about right. The slide shows a complete fall in pulmonary arterial pressure commencing with the first heart beat following the start of the injection. Owing to a slight rise in cardiac output from 4.5 to 6 litres per minute the systemic blood pressure has risen slightly and there is second rise in slow rate of the heart rate. This proves that the acetylcholine is not acting on the systemic circulation. A wholly selective action on the pulmonary vessels is highly desirable when investigating the effect of pulmonary vascular disorders on the physiology of any part of the circulation.

**TABLE**  
**FREQUENCY OF ACTIVE PULMONARY HYPERTENSION**

	Total cases	No of critical cases	Percentage of critical cases		
			R normal	R high	R extreme
Atrial septal defect	197	100	75	9	16
Ventricular septal defect	101	54	26	17	57
Patent ductus	133	45	38	24	38
Mitral stenosis		275	72	16	12
Mitral incompetence		58	86	9	5
Cor pulmonale		35	60	20	20
Primary pulmonary hypertension		16	—	—	100

Critical cases for definition see text  
R = Pulmonary vascular resistance see text

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### Dr J F GOODWIN

I should like to make on two observations on the effect of methionine on the pulmonary circulation in acquired and congenital types of pulmonary hypertension.

In mitral stenosis my colleague and I have shown that methionine in a dosage which only slightly lowers the systemic arterial pressure will cause a considerable fall in the pulmonary arterial pressure without significantly influencing the cardiac output or heart rate. We feel this strongly suggests a release of neurogenic pulmonary vasoconstrictor tone although we cannot with certainty exclude the possibility that the fall in the pulmonary arterial pressure is due to a shift in blood from the lungs to the systemic vascular bed. We think this unlikely however in view of the much greater fall in pulmonary arterial pressure than in systemic arterial pressure. The fall in pulmonary pressure is produced in mitral stenosis after methionine can also be produced in a dose equivalent in pulmonary hypertension due to cor pulmonale. Once however with congenital types of pulmonary hypertension there has been a definite for amplification in the arterial septal defect with very high pulmonary arterial pressure and with a two-way shunt in the lungs as seen through the cardiac catheterised to alter the pulmonary arterial pressure. Methionine would be required to decide whether the difference in response between the two groups is due to a different type of pulmonary hypertension.

### Dr W A BRISCOE

Professor Dillington and I were going to the hospital to see that someone is in the lung field.

occurred was teleologically useful to the organism. This might be true if the lung were only ventilated but the normal lung shows considerable difference between the degrees of ventilation of different parts. Some parts have only half the ventilation of others. Such a lung will transfer oxygen and carbon dioxide most efficiently if perfusion is proportional to ventilation throughout the lung. This would require that the blood perfusion to the less well ventilated alveoli be reduced below that to be expected if perfusion were proportional to the quite large volume of the alveoli. Thus any somotor activity cutting the perfusion of less well ventilated alveoli would be biologically useful. New techniques of interpretation of mixed and arterial blood analyses developed in conjunction with Dr Courmand may be able to detect a disproportionate fall in ventilation in human man.

There has been much discussion of pulmonary capillary pressure. I should like to utter a warning about samples of pulmonary capillary blood taken with a catheter wedged in a small pulmonary artery. The blood has been pushed through the wall of two alveoli and a ventilation-perfusion ratio about twice the normal. It cannot therefore be regarded as representative of pulmonary venous blood in capillary bed.

When I was very young we used to stay late at night during the high cardiac output of some cases of pulmonary hypertension. It was possible to tell the patient at that time we were only on teleological ventilation. An increase in diastolic pressure with arterial saturation results in the delivery of more blood due to more oxygen to the tissue. However, a new usefulness in the high cardiac output may be itself in a future study of ventilation-perfusion. The duration of blood lying in alveoli how well permeable diffusion of gases occurs in the deep for present purposes of the

thing only — (1) The inspired oxygen tension (2) the ventilation perfusion ratio of the alveoli (3) the oxygen saturation of mixed venous blood. When the ventilation perfusion ratio in the normal range or higher (about 10 or more) the saturation of mixed venous blood has very little influence on the saturation of the blood leaving the alveoli. But when the ventilation perfusion ratio is low (about 0.1) the saturation of mixed venous blood is an important determinant of the saturation of the blood leaving the alveoli.

In men with arterial unsaturation due to emphysema there is a very wide range of ventilation perfusion ratios within the lungs and large volume of alveoli may have a ratio which is around 0.1 only on thirty three of the ratio in the well ventilated alveoli. When red cell output is increased to parameters of blood gas transfer are hindered — (1) Ventilation perfusion ratios are reduced (2) the saturation of mixed venous blood is increased. In the well ventilated alveoli this is the dominant factor greatly predominates in importance and leads to a condition in which the saturation of the blood leaving the alveoli is not hindered by the saturation of mixed venous blood. In a typical case of emphysema doubling of the arterial output would have raised arterial saturation from 70 to 81.

Thus we now see that the alveolar ventilation for the high red cell output in emphysema. There is the old time effect by which the amount of unsaturated blood added to the tissues is increased and there is no other pulmonary effect by which the pulmonary saturation of the blood is increased.

## Dr G de J LEE

Dr de Burgh D is has discussed opinion regarding the presence of vasomotor activity in the pulmonary vascular system into three groups — (1) the nihilist who considers the system to be passive on those who consider that vasomotor activity though present is negligible and obscured by passive changes within the pulmonary vascular system and (3) those who believe that vasomotor changes play an active part in pulmonary homeostasis. He has no conclusive evidence with numerous controlled experiments to support the latter group. I should like to discuss some data obtained by Professor Sharpey Schafer and D. Matthe (1954) at St Thomas Hospital from human studies which lead me to hold an opinion of tentative significance.

It is difficult to reach a definite conclusion about the origin of pulmonary resistance change in man that is impossible to control or measure to take volume. We therefore compared simultaneous pressure measurements obtained from the systemic and pulmonary arterial system under circumstances known to produce obvious systemic vasoconstriction. The use of Valsalva's manoeuvre is a convenient way to do this. The brachial artery pressure changes are characteristic. During the period that the intrathoracic pressure is raised while Valsalva's manoeuvre is maintained there is an initial squeeze imparted to the thoracic aorta which produces a short lived sharp rise in the arterial pressure. Then as heart filling is impaired the stroke volume progressively decreases and pulse and mean pressures fall. With the release of the Valsalva's the impairment of venous return to the heart ceases and there is a rapid decrease in stroke volume. This is associated with a marked rise in both

pulse and mean pressures in the systemic artery which sometimes termed the overshoot. Part of this rise in pressure is due to changes in stroke volume but vasoconstriction induced by the period of low pulse pressure during Valsalva's manoeuvre is also responsible. This period of vasoconstriction following Valsalva's manoeuvre can be demonstrated by a fall in forearm blood flow measured by venous occlusion plethysmography (Sharpey Schafer 1953).

The systemic arterial pressure was compared with the effective pulmonary artery pressure obtained by a differential manometer recording the difference between the pulmonary artery pressure via cardiac catheter and the intrathoracic pressure measured from a water filled catheter situated in the oesophagus (Dornhorst and Leathart 1955). The systemic responses have already been mentioned. In the pulmonary artery a similar rise in pressure also occurs following release of the Valsalva manoeuvre (Figure 1). It differs from the brachial artery response in that

Figure 1

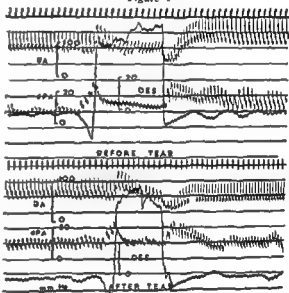


Figure 1 The effect of Valsalva's manoeuvre on brachial (BA), effective pulmonary artery (dPA) and intraoesophageal pressure (OES). There is a marked rise in brachial artery pressure following Valsalva's manoeuvre. This is abolished by TEAB. The pulmonary artery pressure also rises; this rise is independent of bronchial blockade with TEAB.

False pressure changes are made and the phase of expiration also affects the mean and pulse pressure being lower in expiration and higher in inspiration. These changes suggest that stroke output changes are the chief concern with altering the pulmonary artery pressure. As the stroke volume cannot be measured or controlled it was decided as an alternative to block the possible vasoconstrictor effect is also present by using Tetraethyl ammonium bromide. An intravenous dose sufficient to abolish post Valsalva vasoconstriction in the systemic artery was used. This had virtually no effect on the pulmonary artery pressure. However, surge in the flow of the flow of the

Fig 2

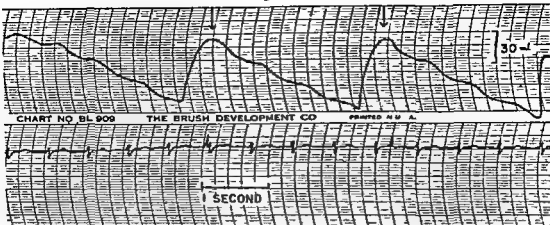


Figure 2. Record obtained during breath hold after  $\text{N}_2\text{O}$  inhalation. Plethysmograph pressure above arterial blood changes in CG shown below. Left moy ph. nt d to atm. pheric pressure at the arrows

pr inn ting th w f sth r c n f m d i y m l r nt occurring in right tral filling pre

W th fore c nclud d that n n m l m troke olum change p d rate s i n f u e n c i n g th pul mon y a t r i d p r e u o d that a s m o t o r f l i a n o t s u f f i c i e n t l y t o p o d e c h n e i n t i l l y the t e h n q d s c r i d

I t m y w e l l b e t h a t w h e n the p l i m o n y t i j v t m o c e d f m a l o w p r e t o h g h r y j e m b y d e w e t h a s c o n t f o r e f f e c t b e m i n j t t T h w o u l d e p l i n the l k o f j n s e n o r n o m l u b j t a c o m p d w i t h t h e f f e c t s o f l a m e t h o r m i n l w e r i n g p u l m o n a r y t y p r e t h t D r G o o d w a n h a s j t d e s c r i d i c o m p t e l y h o r t s c u l a r v t m u h a t h p u l m o n a r y i t o n w i t h t h p p a n t l y l w d g r o f v a s c u l a r t n i t y j t d m o t r a t e d i t r e l l t p r e m e t h t the j l a t i t y o f b l o o d f l w t h r o g h t h m m p u l m o n a r y a r t e r y w o l d r e m a n n t h p l i m n a r y p i l l a r y s y s t e m

R e n t l y n l y C o m r o e d p r i m n t v t t h U n e r t y o f P n v l a n D r D u b o s a n d I w e r b l t i t t h h y p o t h i s m d f t o n o f l a l A t o u s O d i h q u e f o r m e u n g l i n g b l f l w i m n t o f l o w i n t t i n a f l o n t t o c l u l d t (L e e a n d D u b o s 1955)

I f t h n q u e r e q u e d t h a t t h a l j e c t s i n l o w l t l y j l t h m a r p h T h d i f f e r e n t l p r e s e r b e t w a t h h m b e n d m i r c o m p e n s a t i n g h a l e w a m a u d T h y t m w j u r e d t l i t l e t t y a r e e n t w i t t h l d s p l t h i g p h i f r e e f l o w n o m e t f t E t w t m l g i n t t l u t j e c t s I C C A f t o t r o l p e r l t l l j e t t o o k l e n t h o f 100 m i t o c l d h l d h s t t h w i t h t h g l i t o p e n a t g w h b e d f o m t h l n g e s i n t o t h b l o o d f l o w i n g t h g h t h p l i m n a r y c a p i l l a r y t h e t o l u l o m o f g a s e s i n t h l u n g e s a n d h n t h p l t h y s m o g r a p h p r e s e r d e c r e a s e d p e n d a f f l i n p l t h m o g r a p h p r e r e T h a c o n t o u r e o d o f n t r o n l u p t k w a o l t n d (f i g u r e 1) F o m f i r e d r c m p l n l k n o w t h s o l l i s o f

$\text{N}_2\text{O}$  in blood t l n t a n t n o u p i n o a r y c a p i l l a r y b l o o d f l o w r a t e w a s c a l c u l a t e d (F i g u r e 3)

T h a p i l l a r y b l o o d f l o w w a s f o u n d t o b e h g h l y j u l t l A t e t t h p e a k b l o d f l o w t w a s i n t h r e g i o n o f 1.5 l i t r e / m i n T h s o c c u r r e d a t t h e t i m o f t h T w a e o f t h E C G T h s l o w t b l o o d f l o w r a t e o c c u r r e d i n t h r e g i o n o f t h Q T i n t r a l a n d

Figure 3

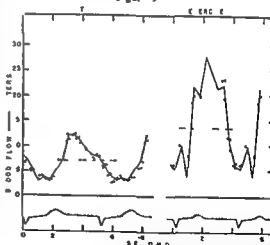


Figure 3. In t n t n o u p l i m o n a r y c a p i l l a r y b l o o d f l o w t a t s n l a f t e r e r e c e Z e o t m l i t r i l y t a k e n t h R w e o f t h E C G s h o w n b e l w c h f l o w c u r c l o s e d a r c l p e n t m t n t u f l w t a t 1.004 s e c f o m t s e c u t h a t c y c l S o l d l p e n t t h e r a g t a t i n o f l w t D o t t d l r e p e n t m n c l o u t p t p e m t e

about 3 litre /min. At moderate exercise the flow rose to approximately 8 litre /min the lowest flow rate being about 6 litre /min.

These enormous changes in flow rate with each heart beat suggest that the pulmonary capillary and intercapillary spaces must be very easily distensible whether this is passive or depends upon critical opening pressure it must be determined. The delay in peak capillary blood flow to the region in contact with the alveoli is when the pulmonary vessels just closing is presumably due to the elastance of the vascular system between pulmonary valve and pulmonary capillaries.

Oxygen uptake by the lung is affected by the available capillary blood flow and its apportionment to the lung is of no highly pulsatile (Lee and Semple 1955). The present concept of gas diffusion and ventilation perfusion ratio within the lung which in the past has assumed that all the blood flow is to the alveoli is affected and therefore being in doubt.

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## Dr W WHITAKER

Working in Dr Brotherton's Department and in the University Department of Medicine at Sheffield Dr Whitaker has treated patients with congenital and acquired heart disease and has examined the following in the pulmonary blood vessels in relation to pulmonary artery blood flow. We have found a low oxygenation.

When the pulmonary artery mean blood pressure is normal or not over 50 mm Hg the pulmonary vessels are usually normal. When the pressure is of the order 50-70 mm Hg a media is found in the pulmonary arterioles and this we regard as the fundamental histological feature of pulmonary hypertension.

The first slide shows four pulmonary arterioles (less than 100  $\mu$  in diameter) from a normal patient and from three patients with moderately severe pulmonary hypertension. The normal arteriole has no media, the all on the outer angle elastic lamina between a thin dentate and intima. The occlusion of the muscular wall. The other three arterioles (top three) pulmonary hypertension pressure 0 mm patient due to artery pressure 65 mm intratone pressure 74 mm all have a definite media. The muscular pulmonary artery (100 to 1000  $\mu$ ) from patients with moderately severe pulmonary hypertension on usually have medial hypertrophy and an abnormal amount of subintimal fibrous tissue but these changes are not so consistently found as the abnormal media in the pulmonary arterioles.

In severe pulmonary hypertension on here the pulmonary pressure is above normal or exceeds the systolic pressure the pulmonary vessels are grossly abnormal. The arterioles and muscular pulmonary artery after

medial hypertrophy and subintimal proliferation of fibrous tissue with occlusion and recanalisation of the lumen. Arteriole necrosis is occasionally found in association with severe pulmonary hypertension (slide shown). The final slide shows an unusual feature observed in a patient with ventricular septal defect complicated by severe pulmonary hypertension throughout the sections aneurysms appeared from the walls of the muscular pulmonary arteries shown on a serial section to be aneurysmal dilatations of branches of the arteries.

In patients with severe pulmonary hypertension and extensive pulmonary vascular disease the signs of pulmonary hypertension dominate the clinical picture and it may well be impossible without specialised investigations to recognise such underlying lesions as atrial septal defect, ventricular septal defect, patent ductus arteriosus or mitral stenosis or to include idiopathic pulmonary hypertension. It seems reasonable to suggest that such patients with severe pulmonary hypertension having similar extensive characteristic pulmonary vascular abnormalities should be recognised as suffering from hypertensive pulmonary vascular disease.

## Dr D V BATES

To a clinical respiratory physiologist provocative marks and ideas have been shot into the air today like clay pigeons and it is hard to know where to shoot first. There are however four points worth mentioning. First Prof. or McIlroy may be mentioned to know that the change in pulmonary blood volume in the posture that he mentioned has been shown by recent work at St Bartholomew's and a Philadelphia to be due at least in part to an actual increase in the volume of blood round the alveoli. Second I must take issue with him over the actual volume of blood around the alveoli at any one time. He mentioned a figure of 1/3 of a litre of blood and contrasted this with the figure of 60-90 cc obtained by Roughton in 1945. A recent report of Roughton's work has shown that the order of error in his estimate of 60 cc is small and at the moment I think this is reasonable to be preferred to that supporting a figure of 750 cc. Thirdly I think it very important to distinguish carefully between pulmonary hypertension caused by different mechanisms. We have recently had an opportunity to study a patient with primary pulmonary hypertension with a very high pulmonary artery pressure in this patient there is no abnormal lung stiffness and no change in pulmonary vascular flow. Contrast this with mitral stenosis and you will also take that in mitral stenosis the pulmonary capillary bed lies between the obstruction and the right ventricle whereas in primary pulmonary hypertension the lesion is situated between the capillary bed and the entrance. The distinctions seem to me important and perhaps have not been sufficient. So finally on the matter of the observation that pulmonary capillary pressure is exceeded in arterial plasma pressure is about pulmonary oedema. With my colleague Dr McIlroy we were recently measuring the physical properties of the lung and the diffusing capacity in a man who had had a pneumonectomy. He was walking at about 3 miles per hour without distress when we noticed that the lung was becoming progressively stiffer and the gas maintenance of a normal minute volume and the gas diffusion was steadily falling. These are the changes

of d elop ng pulmonary oedema We stopped the treadmill the patient walked back to h char and ther was at no time clinic l m idence of pulmonary oed m I menti n this patient to illustrate the possib lty that gnic nt tran udation may occur accoss the lun cap llaries without this being clin cally obvious as grow pulmon y oedema

## Professor MELVILLE ARNOTT

Emphas was placed on the f ct that th elevat on of pulmon y capillary pres ure to a level above the oncotic p e u might not be a my tenon a st fi t pears It must frequently h pp n during state of pulmonary oedema th t the p sure is r sed well aboe on ot c pre u e for prolonged p rods and th il condole amount of protein r h fluid escape into the l oli Only a fr ction of this is coughed up the m m bulk of th ng to t removed a the lung nd lymph t cas It might w ll be that the impo nt f cto us ng severe pulmonary oed ma s a gradual det oration of th lung lymphat c n the r c p c ty t r mo e fluid Ind d there might be the develop ment in the l g of a sort of ch on c ndurative t t som what an logous to the lymph oedema th t oc uss in the y tem c ulation n ar ose n f th lo lmb and i f n s

## Sir RUSSELL BROCK

I would lik to congratulate Professo Liebo on th pec m n h ch h showed us n his add Those of us who h e kn wn h s work have dmured it for many y m Th s one aspect of h s demon t ton on ond ry pulmonary y t m c commun tio th t I would l ke to discu s He ind cat d that such second y commun ations may b of mpo tance in regard to th as ularisation of the myocardum of th ventricles in c es of myocard l ischa mia To support this l e d s b d r t n forms of ne s m which l o l l o s d and demonstrated Th one ar ety of th secondary ve sel f mat on which he efe red to only b fly nd which I would lik h m to cl nfy Th t th form t ion of d ct n stomach between the ve el of the l m nd the co on ry ve el on th u fce of the entricles lfe nd ted th t m operation of c do-pn unopoe y might be of on d r bl aluo in provid g u ful and m po t nt second y blood s pply to the d sased myc rium Th s ob ously a matter of fa d m t l mport e n relation to the p nt tent on th t is be ng p d to u gic l method of impro i go m t g t c o y sch m Tho of n who h ope t d on th h art and lung may h e obser ed n t f tu th t I h m obse d myself To t nce m of p lmonary stenosis nd i rticu l r l n a of c rre pulmon y t no mo t n to tr a the presence of the l rge collater l c ulation only too o of ou d e e c lly s th so n c m which a w o d operation l ng perform d H re th adies bet n th ch t wall nd th lu g full of lurg sel which bled so freely when th v d d th t the p s t n m s be s ng uated d t n r be n cess ry to h ndon the operation How r it h n been my p en nce to ol r m l free w s sel f m t n between th lu m and the urf of th heart itself Professor I elbow descnbe l

the retro c rdia c an stomot c v ssels which he emphas ed and which re similar in character to the anastomo e between the lung and the chest wall That s anastomo c between the coronary c ulation and mediast nal v ssels These vessels he displayed cl arly and pre ely in all h s spec mens He did not show quite so cl arly however the vessels th t occu between the surface of the lung and th surface of th entricles I ha e re op rated on a consid able number of c es of heart d se both cong n tal and acqu ed lesions such as mitral stenosis and I have fa led to observe any vasculat ion of mportan e in adhesion bet een the su face of th heart nd the pericardum or the adjacent lung In f ct it is my p c t ce when ope at ng on a h art ca c as a f t step to fre the whole of the he rt from th p ricardum in m der to be bl to pply cardac m sage eff c tly hold t pro e n cessary In doing this fre ng unl ono d id f o nstance a co onary es l there no ble d ng Th re s no evidence of new c el In addit on when I con lude n operation on the hea t l the pericardium loosely o that apertures rem n At re ope at on the aperture till pe ct can b sly recogn d and through them th u fce of th hea t s nd rect cont ct with the lung t e Agai I would emph s e that it s not u ual to find any aacula conn ctions acro th s pnce Th t s th problem th t orries m

## Professor LIEBOW

When Sir Ru ll Brock repo ts on an op tve f d n m n that appea s ncompatible with th p ments that h e ben ported he must be g en th clo t t n on The transperic d al ollateral w r not emphas sed during the pre nt t on s nce th was the xp sed find ng it was the demon tration of the t o d ollateral that was not expect l nd that was therefore presented in great d t l In his op t on man Sir Russell was deal ng uth with norm l lun s or with lungs in which the ollateral blood supply h d already b com e t b lish d In th pr sent experiments howe e th pul monary artery l gat d at the tm of th r d o p um opoxy und th s cumstances the lung at on e becomes a very blood thirsty a g n A part of th th t t f d by p n f th no m l bron h al t l s pply from th hilum the remainder come from th p on of es el th t o fo m d as g nulation t s u with n adh ons In the ours of m th es c n lge g exth to the s e of arterial es l nd the microscop at l quite com p t bl Th s qu e el tic t s ue and muscle as would be expected of l of r l type and simi lar The actual tran pericard oll t l th t w ho n on the c s had cros sectional diam t of p r o mateh l mm Num ou m l l e s e s n ob r d n l l of th h arts thus treated l y d opoe unopoe y after l gatur of th pulmonary lery Th sel n c l l ger than thos fou l n o d nry shes on fo e mpl wh m the per ardal m d to form g nulation t s ft njection of silica du t Unker th r m t ces they s too small to be nject d with th j l t u d n th prep t on l the c t It s s rpe ng that n th pr se t perum nt n actu l l a f of blood from the coll t l rculat ion to the coron rter wa d m o t rted wh n t might be pected that th blood pres r n th coron ry t s ho ld ed that n th coll laterals



It is not reasonable explanations that the pulse pressure was in the two arterial system or out of phase

## Dr DOSS

I want to make a few remarks about pulmonary hypertension in Egypt caused by schistosomiasis. The ova of the Bilharzial worm from the bladder region pass to the lung and are caught in the arterioles of between 50 and 100  $\mu$ . They penetrate the vessels producing an inflammatory reaction with endarteritis and often in addition an anastomotic formation. We used to think that these anastomotic formations connected the occluded vessels with the pulmonary veins or the bronchial arteries. But I see that in the demonstrations here Dr Bird has followed up similar anastomotic formations in another condition of pulmonary hypertension and has found they interrupt the proximal and distal parts of the same vessel. One of the characteristic features of our cases is the peripheral oligæmia as seen in the X-ray picture. The vessel is from the hilum to about two thirds towards the periphery are seen to be dilated and then the vessel markings disappear. This would seem to indicate that peripheral to the obstruction produced by the inflammatory reaction no blood is flowing. As some speaker pointed out a little while ago it seems strange that a localised lesion like the ones we observed could cause pulmonary hypertension. In many cases the lesion produced by the Bilharzial ova are quite widespread and it would seem understandable that in such cases they would produce pulmonary hypertension. But in other cases the lesion is a very limited and restricted one and yet even in those cases some degree of pulmonary hypertension is very often present. This raises the possibility of some functional factor playing a role so we embarked on the following experiments. We injected between 23 and 30  $\text{mg}$  of hexamethonium by cardiac catheter into a branch of the pulmonary artery and noted the mean artery pressure before and after the administration. After hexamethonium the pressure dropped considerably in a few minutes sometimes dropping from as high as 90 to as low as 3 or 30 mm of mercury. In normal control the pressure dropped from an average of about 13 or 15 mean artery pressure to 8 or 9 or 10 mm of mercury. It was obvious from this the effect that in the cases with pulmonary hypertension the pressure was partly due to a structural narrowing but more is due to an increase in the pulmonary vasomotor tone. The possibility that changes in the cardiac output had caused this drop was ruled out by the fact that very little change of any occurred in the cardiac output. This corresponds with the work of Professor McMichael who also showed in some patients that the injection of hexamethonium did not bring about any change of cardiac output although it did bring about a drop of the pulmonary artery pressure. We are at present investigating the factors present in those patients with the highest pulmonary artery pressure.

## Dr C M FLETCHER

I have a question to ask and a comment to make about Professor Gough's paper.

The Question—How can a fibrous mass occupying not more than a third at the most of the lungs produce pulmonary hypertension no matter how severe it is affected at the vessels in the mass if as appears to be in some cases the rest of the lung is almost normal?

The Comment—Professor Gough told us that the SMR for Myocardial degeneration in 1951 was 186 for coal hewers and getters and 110 for other mine workers but these figures cannot be assumed to indicate an occupational origin for the excess mortality of these workers for their wives have an even higher SMR namely 111 and 179.

## Professor GOUGH

In the obstructive form of pulmonary hypertension in massive pneumoconiosis the blood vessels in the masses may be almost all destroyed but the main vessel leading to the masses not only remains patent but is dilated. The right heart has thus the mechanical disadvantage of maintaining the column of blood against only a small resistance as only a very small proportion of blood pumped into these vessels can find a peripheral way out.

With regard to Dr Fletcher's comment on the death rates my theme was that there has been a relative deterioration in the expectation of life of coal miners since the beginning of this century when compared with other male occupation and it can be of little consolation to these miners if they are now nearly as badly off as their unhealthy wives (SMR 1951 All causes Heers and getters of coal 153 their wives 148).

## Dr K W DONALD

Dr K W Donald pointed out that Professor McMichael's contention that underestimation of blood

with cyanosis would occur with anable and phac alteration in pulmonary capillary flow was not necessarily true as such changes may not alter the alveolar ventilation-perfusion relation and that in any case appropriate changes in local ventilation may also occur. His observation that the percentage of blood volume in the pulmonary capillaries were five greater than suggested by Fick's calculation did not seem to be accounted for by invoking that part of the capillary bed where under normal conditions almost complete gaseous equilibrium had been reached and no significant gas exchange was taking place. In diffusion studies using carbon monoxide the gas transfer occurs over the whole length of the capillary. With regard to Dr Wallace Campbell's interesting observations concerning the conduction of pulmonary arterial pressure after mitral valvotomy it was important to define how much of this was due to the pressure in the left atrium. It is also interesting to note that the right ventricle of many of

the patients after operation was demonstrably more work as although the was usually some decrease of pulmonary arterial pressure the cardiac output was far greater than before operation both at rest and on exercise. Further the patient were able to exert themselves considerably throughout the day.

Dr Donald also stated that he felt the importance of the direct left atrial pressure recording and their comparison with wedge pressure had not been fully appreciated as without such evidence wedge pressures and all estimates of pulmonary vascular resistance using these values would mean very little.

There is one hypothesis concerning the importance of pulmonary vasoconstriction in the distal that had not been mentioned. It is possible that muscle hypertrophy of the vessel with abnormally increased vascular pressures may cause a degree of effects of vasoconstriction that could not be possible in the healthy one.

## Studies Of Left Auricular Pressures In Man

P. R. ALLISON (Radcliffe Infirmary, Oxford)

The position of the left auricle below and between the two main bronchi makes it easily accessible to puncture through the bronchoscope. We have already done this on 157 patients without any resulting complication. In the first place the investigation was undertaken in an attempt to distinguish between mitral stenosis and mitral incompetence and also in the hope that the findings might provide a pre-operative assessment of the degree of stenosis. Only in more recent months has puncture of the pulmonary artery and the aorta—by the same method and at the same time—been made a routine procedure in the examination of mitral disease.

Our clinic has been something of a general pool for heart disease but there has been some selection inasmuch as the patients were referred for possible surgical treatment. Apart from this all patients with mitral disease had a left auricular puncture except for the occasional one where mitral stenosis was associated with pregnancy or easily induced pulmonary oedema.

The use of a needle fixed to a Jackson suction cannula and connected to a Hansen capacitance manometer has already been described (Allison and Linden 1953). Since then thicker polythene tube has been used between the cannula and the manometer with a reduction in the number of artefacts but attempts to do away with the tube altogether so that the manometer was attached

directly to the cannula were unsuccessful because the apparatus became too heavy to use with accuracy. If the tubing is allowed to oscillate at all marked irregularities appear in the tracing.

A few normal curves were obtained by auricular puncture of patients being bronchoscoped for bronchial carcinoma. Series of tracings were then taken from patients both fibrillating and in normal rhythm with mitral stenosis incompetence or with mixed lesions. It seems possible to draw a few deductions from the study of these 157 curves done so far.

Although the general shape of the curve may suggest either stenosis or incompetence no reliance is to be placed on this. Any conclusions must be based on a mathematical analysis of the curve rather than on its general form. In this particular the formula for the mitral value

$$\frac{P_v - P_z}{P_v} \times 100$$

as suggested by Linden (Allison and Linden 1955) has proved to be much more reliable than the analysis used by Facquet (1954) or the formula suggested by Wood and Owen (1955). Linden's formula has been brought up to date on this series and in only very few patients were the operative findings at variance with the formula. In these records there are occasional examples in which the shape of the curve sug-

gested regurgitation but which on analysis indicated stenosis and where operation confirmed the result of the analysis. Similarly one or two typical looking stenotic curves proved both on analysis and at operation to be regurgitant. It is wrong therefore to speak of typical stenotic or typical regurgitant curves from the shape alone. The relation of the curve to the base line is all important.

The second deduction is that the most reliable curves are obtained with the slower heart rates. This is in agreement with Facquet (1954) who suggests that the heart rate should be kept below 100 if possible. To achieve this digitalis and morphia may be necessary. Atropine should be avoided and probably most important a close relationship and understanding should be established between patient and operator to reduce fear. The bronchoscopy should be performed gently and smoothly.

The third deduction is that the diseased mitral valve is not always either stenotic or incompetent. During most of the cycles a stenosed valve may be quite competent and then during one or two beats regurgitation may occur. This has been observed only in a fibrillating heart and occasional incompetence may be apparent after a long diastole. The phenomenon is certainly influenced by heart rate and the findings on the tracing can often be confirmed by the finger in the left auricle at operation.

It may be said that the diagnosis of mitral stenosis can usually be made fairly accurately by other means without the need of left auricular puncture. This is undoubtedly true but there are occasions in our experience when this has not been so. An example is D.G. a very fat woman of 44 years who had been a nursing sister now bedridden from breathlessness. She had had numerous attacks of heart failure and two large hæmoptyses. She was very cyanosed, the heart was greatly enlarged and the only consistent abnormal physical sign was a systolic murmur at the apex. If it had not been for her own insistence on surgery she would never have been sent to the clinic. By bronchoscopic examination her pressures were found to be—Left auricle 52/32 pulmonary artery 87/52 and aorta 180/120 in cms of water. This gave a mitral value of 31 which for a fibrillating heart meant stenosis. At operation uncomplicated tight stenosis was found and a good split back to the ring obtained at both commissures with no trace of incompetence.

The relations of the left auricular pressure to pulmonary arterial and aortic pressure at bronchoscopy and later with an open

thoracotomy were noted in this and a few other recent patients. This work perhaps merits comment even at this early stage (see table).

D.G. 44 years Tight mitral stenosis			
	Pressure in cms H <sub>2</sub> O		
	Left auricle	Pulmonary artery	Aorta
On thoracotomy	52 3	87 57	180 10
Open thorax before commissurotomy	30 13	82 45	68 34
Open thorax after commissurotomy	14 4	37 13	60 33

In this patient the anaesthesia and the thoracotomy lowered the left auricular pressure appreciably, the aortic pressure drastically and the pulmonary artery pressure not at all. After commissurotomy the left auricular and pulmonary artery pressures fell to normal without any improvement of aortic pressure.

In another patient a left auricular pressure taken through the bronchoscope was 60/29 and at open thoracotomy 50/22 which represented very little fall if any. In this same heart a pre-operative pressure in the pulmonary artery, both at bronchoscopic puncture and cardiac catheterization was 160/80 falling at thoracotomy to 90/47 whereas the aortic pressure fell from 130/90 to 64/41. It seems that if the left auricular pressure is high from mechanical obstruction it is not grossly affected by the influences that may bring the aortic pressure tottering down with or without a fall of pulmonary artery pressure. In short the higher the left auricular pressure the less dependent it is on extraneous circumstances other than relief of the mitral obstruction. One patient with a left auricular pressure of 26/10 had only very mild obstruction and his pressure fell from this to 6/1 at operation without any fall at all in either aortic or pulmonary artery pressure. A corollary of these findings is that deductions drawn from single estimations of left auricular pressure without relation to the conditions under which they are taken are as meaningless as those taken from similar observations on arterial pressure which is about what we would expect.

On the very few observations made so far and for obvious reasons these have been confined to patients with mitral disease hoping for treat-

ment it seems likely that the left auricular measurements made by direct puncture bear a close relation to the pulmonary wedge pressures when the left auricular pressure is high. It does not follow by any means that the same applies when the left auricular pressure is low. These are problems that need further investigation.

Another question of interest was whether the pressure in the left auricle at bronchoscopy gave any indication of the degree of stenosis. The answer to this was likely to be somewhat vague inasmuch as the estimation of the effective size of the mitral orifice at operation could lay no claim to accuracy. The variation of the flow with the fourth power of the radius greatly increased the inaccuracies of estimation of the size of the opening. Without being able therefore to present

a series of figures on an elegant but deceptive graph one can still say that the highest figures of left auricular pressure indicated the tightest stenoses. Certain it is that with typical signs of mitral stenosis no matter what the symptoms there is no indication for operation on the valve if the left auricular pressure is low. The possibility that in such patients the symptoms have a psychological basis or arise from pulmonary disease and not mitral obstruction must always be carefully considered.

The relation in this series of the left auricular pressure measurement to the lymphatic flow from the lungs as indicated by the fine horizontal lines in the costophrenic angle is being investigated by Rossall and Gunning and will shortly be reported.

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# Vasculitis In The Lung

A C LENDRUM (Department of Pathology Queen's College Dundee)

The understanding of the pathology of the lung in cases of mitral stenosis had a curiously static history until some 15 years ago. Till then it was little more than venous congestion and brown induration. Then it came to be realised that the distribution of the hæmosiderin containing phagocytes is sometimes strikingly focal (Lancet 1952) and this led to a fresh interest in the pulmonary circulation. Next came the observation that in some cases of mitral stenosis the arteries show changes recalling polyarteritis nodosa and close on the heels of this cardiac catheterisation arrived.

This so called arteritis merits attention because our conception of this condition will depend some of our speculation on the pulmonary circulation. Two main lines of thought have arisen. One group regard the changes as comparable with those occurring in malignant hypertension since the changes had been observed in cases showing the morbid anatomical features of pulmonary hypertension. The other group while admitting the presence of hypertension regard the histological changes as more closely resembling those in polyarteritis nodosa. This

impasse has stimulated further study of these and comparable conditions and a new viewpoint is now offered.

Firstly it may be noted here that the lung showing arteritis or better vasculosis may have no focal hæmosiderosis and in one case in which both abnormalities were present there was an absence of vasculosis only in the regions where there was obvious focal hæmosiderosis.

The vasculosis is seen as a deposition of fibrin in the walls of the pulmonary arteries ranging from 450  $\mu$  down to those of 50  $\mu$ . These sizes are measured on involved arteries and arterioles but the affection may well have led to widening. To summarise my interpretation of the changes fibrinogen enters from the lumen and fibrin is deposited under the endothelium. Where the intima is thickened it is possible to see a piling up of the fibrin on the inner side of the internal elastic lamina in the same way as Anitschkow (1933) noticed with the lipoids in cases of experimental hypersterolaemia. The fibrin then appears to break through the elastica traverse the media and again be partially held up at the external elastica with the result that it may

pread laterally for quite a distance on the inner side of this membrane. Finally it erupts through and fins out in the adventitia. One presumes of course that the substance that spreads is fibrinogen the material one observes gives the staining reactions of fibrin (particularly by the picro Mallory method). In some of the affected vessels there is now seen a gathering of cells, many of which are polymorphs very few are

### FIBRINOUS VASCULOSIS

Static type	Infarction and torsion
Hypertensive type	Malignant hypertension
Hyperergic type	Drug induced vascular disease toxicity of it polymorphous

eosinophils and some are recognisable only as nuclei which show extraordinary elongation and distortion to tadpole forms or angled matchsticks. These distorted nuclei are a very unusual and striking feature.

Study of a series of other vascular lesions has led to the discovery that a similarly distributed deposition of fibrin occurs in cases of drug induced vascular disease (hyper sensitivity

angitis Zeek) in the kidney of malignant hypertension and in tissues that have undergone infarction or torsion. The peculiar nuclear distortions noted in the lungs have also been seen in all these other diseases. As it seems clear that an identical histological picture can be produced in these different diseases granted that the main brunt may fall on vessels of different calibre in the different diseases we can now regard the changes in the pulmonary arteries as a form of fibrinous vasculosis.

Fibrinous vasculosis would seem to be the result either of abnormal permeability as in the static and hyperergic types or of abnormal pressure as in the hypertensive type. If one of these precursor states is known to exist in any given case we ought surely to relate the fibrinous vasculosis to that state and thus in these cases of mitral stenosis I believe it is proper to attribute the change to hypertension. In the pulmonary circulation therefore we are left with the same problem as faces us in the systemic circulation. What is the extra turn of the screw that in a few cases pushes up the pressure forces fibrinogen into the vessel walls and changes the relatively benign into frankly malignant hypertension?

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*I am glad to acknowledge material for study from a group of generous colleagues so numerous that they must unfortunately be nameless here*

## Pulmonary Function In The Newborn Lamb

G S DAWES (The Nuffield Institute for Medical Research University of Oxford)

The investigation of pulmonary function in the newborn baby is very difficult not least on ethical grounds and there is therefore good reason for studying the newborn lamb. While the most that this can contribute is to define some of the factors which may determine survival in the baby it is interesting that these should include the beneficial effect of a patent ductus arteriosus in the presence of pulmonary arteriovenous shunts a phenomenon which has been so successfully exploited by modern thoracic surgeons.

In the mature foetal lamb the carotid arterial

O<sub>2</sub> saturation is normally about 60% it falls precipitously when the umbilical cord is tied and as the lamb begins to breathe rises slowly to 90% over a period which is sometimes as long as several hours. In the foetus the lung uses about 10% of the oxygen uptake of the whole lamb so that the blood in the pulmonary veins contains less O<sub>2</sub> than that in the pulmonary arteries. Any part of the lung in the newborn lamb which is not expanded therefore will not merely act as an intrapulmonary arteriovenous shunt but may actually abstract O<sub>2</sub> from the blood passing through it.

When a fetal lung is ventilated for the first time its vascular conductance is increased and more blood flows through it at a lower pressure. This increase in pulmonary blood flow after birth causes a rise in left atrial pressure and hence assists in the permanent closure of the valve of the foramen ovale. There is another factor which operates in the same way. Before birth about 60% of the combined output of both ventricles flows through the placenta and thence up the inferior vena cava. Consequently, when the umbilical cord is tied and placental blood flow ceases there is a considerable fall in pressure in the vena cava; this alone is sometimes sufficient to reverse the pressure gradient across the foramen ovale. Nevertheless in many lambs for a short time after birth blood may continue to flow through the foramen ovale constituting a pulmonary arteriovenous shunt outside the lungs.

The deleterious effects of the two types of pulmonary arteriovenous shunt: to some extent offset by the continued patency of the ductus arteriosus. In the newborn lamb more than half the total pulmonary blood flow may pass from the aorta through the partly constricted ductus shortly after delivery giving rise to a murmur and thrill in the pulmonary trunk. If the ductus is occluded the pulmonary arterial pressure falls, aortic pressure rises and there is a reduction in the %O saturation of the systemic arterial blood (Fig 1). Experiment on adult dogs have shown that the beneficial effect of a patent ductus arteriosus can be explained by and quantitatively predicted from the consequent increase in pulmonary blood flow: whether the pulmonary arteriovenous shunt is outside the lungs (as in the tetralogy of Fallot) or within their substance.

In lambs the ductus arteriosus normally constricts within 15 minutes of beginning ventilation though it is not functionally closed for many

hours. A major factor in determining this constriction is the  $pO_2$  of the systemic arterial blood (Fig 2). A fall in  $pO_2$  causes dilation of the ductus and a rise causes constriction either in the fetal or newborn lamb or in an isolated heart-ductus preparation. This phenomenon has been observed in the absence of the lungs and central nervous system and independently of changes in blood pressure. Profound anoxaemia sometimes also causes the ductus to constrict temporarily. This is probably due to liberation of sympathetic amines since the effect can be imitated by infusion of adrenaline or noradrenaline into the fetus.

While these circumstances may promote survival in well ventilated lambs in under-ventilated lambs systemic arterial pressure rises and yet does not exceed pulmonary arterial pressure. The physical conditions which limit inflation of the lungs are therefore of great interest. The pressure required to inflate fetal lungs is considerable: 30 or more mm Hg and mature lambs can produce intrapleural pressures as low as -50 mm Hg. In mature lambs positive pressure ventilation causes an initial rapid increase in distensibility (tidal air/tracheal pressure) followed by a slower increase over many hours. The lungs of premature lambs are much less distensible (per kg body weight) than those of mature lambs and the failure to obtain a sufficient increase in pulmonary blood flow on ventilation is probably the ultimate limitation to viability.

It will be apparent from this brief account that there is ample room for more detailed investigations of pulmonary function in the newborn. Yet before the elegant and ingenious methods of human physiologists can be fully applied it may well be necessary to understand the vagaries of the circulation in the human baby in more detail than is yet available.

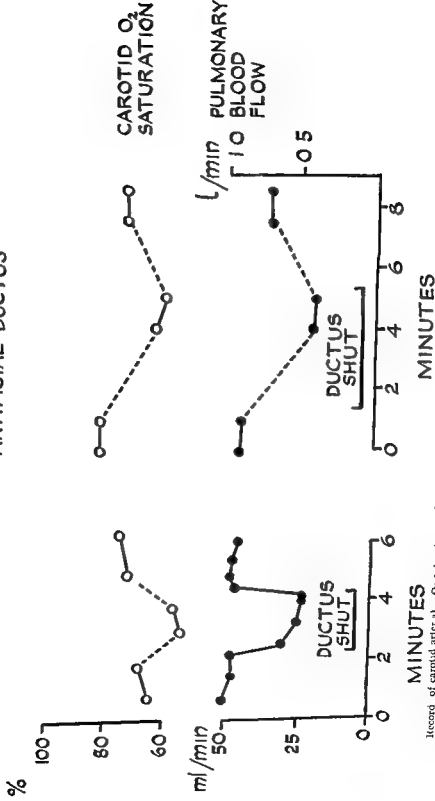
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- I am most grateful to my colleagues Joan Mott, J H Huddicombe, G V R Lorn and Barbara Pennick who have collaborated in this work.

## NEWBORN LAMB

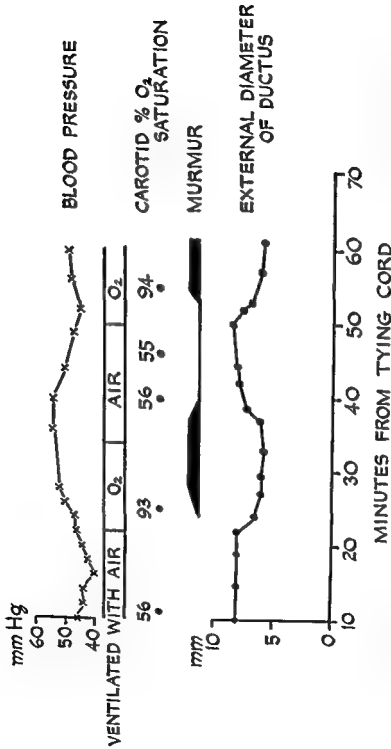
## ADULT DOG

### 2 LOWER R BRONCHI OBSTRUCTED, ARTIFICIAL DUCTUS



Record of carotid artery O<sub>2</sub> saturation and of pulmonary blood flow in a mature lamb (left) and in a newborn dog (right) by direct Fick principle. In the dog an intrapulmonary arteriovenous shunt of the ductus arteriosus was closed to the pulmonary trunk to form an artificial ductus arteriosus. CLO are

Figure 2



Mixture of nitrite and by cyanation pentobarbitone anesthesia. Postoperative ventilation with O<sub>2</sub> causes an increase in carotid O<sub>2</sub> saturation and reduction of the ductus arteriosus (external diameter measured with calipers) with the appearance of a murmur in the pulmonary trunk.



# Respiratory Function Estimation For The Physician

W MELVILLE ARNOTT (Department of Medicine University of Birmingham)

The quantitative assessment of respiratory function by the clinician until some 15 years ago scarcely went beyond the measurement of respiratory rate and of vital capacity. Since then there has been a rapid accumulation of precise quantitative data from the newer methods of clinical measurement and it has become possible for the physician to think in terms of the underlying mechanisms.

The function of the lungs has been defined by A. W. Donald (1953) as the maintenance in the arterial blood of normal and nearly constant oxygen and carbon dioxide content and tensions under all physiological conditions and doing so without causing any undue sensation of ventilatory discomfort or any adverse effects on the heart or other organ. Dornhorst (1952) in an analytical assessment of respiratory function regard the respiratory system as a supply channel whose activity can be characterised by its conductance which is the function relating the rate of passage through it to the pressure difference between its ends. This channel transmits oxygen inwards at rates varying from 150 to 1500 ml/min and transmits carbon dioxide outwards in approximately the same volumes. It is a marvel of integration that gases so dissimilar in concentration, diffusibility and in mechanism of chemical transport in the blood stream should pass so smoothly and efficiently in opposite directions along this channel.

From the point of view of clinical testing this channel is divisible into three zones: (1) the passage from the mouth to the alveoli flow along which can be regarded as ventilatory function; (2) the mechanisms of diffusion from the alveolar gas phase through the alveolar wall into the capillary blood stream—or diffusion function; and (3) the hemodynamics of pulmonary capillary blood flow or circulatory function.

In these three divisions of respiratory function particularly the ventilatory, it is almost fatally easy to find measurable characteristics and to amass figures. Objectives must be kept clearly in view. Physiological procedures may aid the clinician either as diagnostic aids or as a means of assessing severity when the diagnosis is not in doubt. Again quoting from Dornhorst (1952) the justification of a diagnostic test is statistical, depending on whether on the average it improves classification

of patients to an extent commensurate with the effort it entails.

I propose to outline briefly with their clinical significance the more important tests of respiratory function leaving those concerned with gas diffusion—across the alveolar capillary membrane—to Dr Bates who has been deeply engaged in this aspect.

## Ventilatory Function

The measurement of the static lung volumes has been extensively practised and has shed a certain amount of light on lung disease. The residual volume is usually measured in this country by the closed circuit helium dilution method of McMichael (1939) as modified by Meneely and Kaltreider (1941) and in the U.S.A. by the open circuit nitrogen wash out method of Darling, Courmand and Richards (1940). Normally the functional residual capacity is about half of the total lung volume and the residual volume varies from 20 to 40% of the total lung volume. Higher values are found in older people. It must be emphasised that it is quite likely that values somewhat in excess of 40% may be found in a few healthy people so that diagnostic reliance must not be placed on this test alone. Many of the departures from normal are clearly related to obvious structural change and do little to illuminate the situation. For instance in massive consolidation lung collapse without air trapping partial or complete pneumonectomy &c the total lung volume and in proportion its subdivisions are reduced. The characteristic of emphysema is a normal or slightly increased total lung volume with a disproportionate increase in residual volume resulting in a residual/total lung volume ratio of above 0.5. However the relationship of this increase to the degree of disability as assessed by the arterial blood desaturation at rest and with exercise by the amount of carbon dioxide retention or by the extent of pulmonary hypertension is inconstant (Baldwin et al 1949).

The syndrome of pulmonary fibrosis due to a wide variety of pathological processes has the obvious effect of restricting pulmonary distensibility consequently reducing the total lung volume and the inspiratory reserve volume without altering the other absolute measurements. The result is reduction in vital capacity and increase of the residual/total lung volume ratio.

Both the open and closed circuit methods of measuring functional residual capacity provide opportunities for measuring the rate of gas mixing. The abnormally high concentration of alveolar nitrogen after seven minutes' quiet breathing of oxygen and the unusually long time taken to achieve closed circuit equilibrium in respect of helium both in emphysematous patients illustrate the gross inadequacy of alveolar ventilation in that disease.

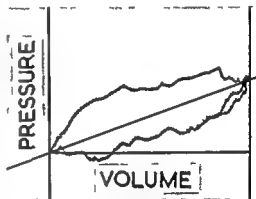
Lung volumes of course are pure statics. A dynamic test which embraces rate of volume change is the Maximum Breathing (or Ventilatory) Capacity in which is measured the amount of air breathed in any given time which may be as long as 15 or as short as 1 sec. The result is expressed in litres/min. At first the test was often done by urging the patient to breathe as hard as possible leaving the patient free to choose his own frequency and amplitude. Nowadays it is more usual to control the rate at frequencies of 50, 60 and 70. The work of Bernstein, d Silva and Mendel (1952) in designing a spirometer capable of responding accurately to these high frequency phase reversals has greatly improved the value of the test. As the ordinary Benedict spirometer is virtually useless for this purpose the only alternative method is the collection of expired air in a Tissot spirometer or a Douglas bag. In assessing the value of this test Donald (1953) has emphasised that although it is a useful measure of the pumping capacity of the chest many attributes of this activity are being tested simultaneously. Furthermore there is this element of unreality about it that the amount of air that can be breathed is in the healthy about twice the amount ventilated by a normal person subjected to the most powerful physiological stimulus. This test remains the best overall yardstick of ventilatory insufficiency without any great capacity to differentiate the nature of the fault.

Much work has been done on the cost of ventilation in terms of ventilatory volume per unit of work and in relation to the maximum ventilatory volume. This will gain in value to the clinician as normal standards in respect of age, sex &c emerge.

There has recently been a revival of interest in a method of studying the work of breathing devised some 30 years ago by v. Neergaard and Wirz (1927) mainly by Otis Fenn and Rahn (1950) in America and Christie, Marshall and McLeroy (1954) in this country. This consists of the application to the bellows action of the lungs of the principles the engineer employs in studying the physics of pumps and heat engines. The central point is the construction of a pressure

volume (P-V loop) diagram of air pressure and volume in the lungs throughout a respiratory cycle (Fig 1). The major axis joining the points on the loop corresponding to no-flow at the height of inspiration and the depth of expiration forms the hypotenuse of a triangle whose area is proportional to the work done in overcoming the elastic recoil of the lungs while the area enclosed by the major axis and one boundary of the ellipsoid is proportional to the work done in overcoming the viscous and turbulent resistance to air flow and the viscous resistance to deformation of lung tissue. Already this technique has shed much light on the mechanics of breathing in respect of the physiological factors governing the relationship between frequency and amplitude of breathing in the setting of the resting respiratory level and in the distorted mechanics of lungs stiffened by disease and air passages narrowed by thickening and spasm of their walls. At present it is a research procedure but it is quite likely there may evolve from it comparatively simple tests applicable to routine clinical practice.

Figure 1



The loop of intra-oesophageal pressure and tidal volume (Arnott, W. M., Butler, J. and Ince, A. C. 1954)

### Circulatory Function

The most useful blood test of respiratory function open to the ordinary clinician is the estimation of the oxygen and carbon dioxide contents of a sample of arterial blood withdrawn preferably from the brachial artery. The routine practice of this procedure has revealed how severe may be the arterial unsaturation in many forms of respiratory disease. A glance at the dissociation curve of haemoglobin reminds us that a reduction of only a few per cent in oxygen saturation represents a gross depression

of oxygen tension. This test can be made much more revealing if performed immediately after exercise (always supposing the patient be capable of this) because often enough ventilatory function is sufficient to maintain normal arterial saturation at rest but quite inadequate to cope with increased oxygen uptake. Any defect such as emphysema which seriously impairs alveolar ventilation raises the carbon dioxide content of the blood. The importance of this factor in the production of the carbon dioxide narcosis

sometimes seen in severe cases of emphysema treated by oxygen inhalation was pointed out by K. W. Donald in 1949 and has since received much attention notably by Westlake, Simpson and Kaye (1955).

In conclusion I would emphasise that brevity has resulted in a very sketchy survey (not including bronchspirometry) of this subject and that the most important subject of gas diffusion and ventilation perfusion relationships is left in the safe hands of Dr Bates.

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# Gas Diffusion And Lung Function

D. V. BATES (Dunn Laboratories St Bartholomew's Hospital London E.C.1)

The study of the process of gas diffusion in the lung illustrates the universal difficulty of applying simple physical laws to the field of biological investigation. The characteristics of a membrane A in terms of diffusion through it of a substance x may be defined as follows —

$$\text{Diffusing capacity} = \frac{\text{Volume of } x \text{ transferred in } t}{\text{Gradient of pressure of } x \text{ across } A} \quad \text{cc. min./mm. Hg}$$

Gas diffusion is of physiological importance in the human lung since oxygen has to pass by diffusion from alveolar gas to red cell haemoglobin. We may recognise at once several factors intimately concerned with the speed at which this process can occur, an obvious one being the permeability to oxygen of all the structures that separate the gas from haemoglobin. Since oxygen must pass into haemoglobin the rate of transfer as it will be measured is in addition affected by the surface area of haemoglobin exposed continuously to the gas and by the kinetics of the reaction between O<sub>2</sub> and Hb.

The methods that have been devised to measure the pulmonary diffusing capacity for

oxygen are complex and limited space precludes any detailed discussion of them. The evident difficulties in calculating the oxygen pressure across the alveolus have been brilliantly surmounted by Lillenthal and Riley but the method remains a formidable technical procedure. Ever since the pioneer work of the Kroghs in 1910 the use of carbon monoxide for the investigation of pulmonary diffusion has seemed the method of choice and this technique has been simplified by the introduction recently of physical methods of gas analysis applicable to carbon monoxide. The rate of diffusion of CO from the lungs (Dco) may be measured either by a single breath or by a steady state method. Each of these possesses advantages and disadvantages in practice but so far all available evidence suggests that the two methods give results of the same order of magnitude.

What has been learnt so far of the nature of gas diffusion in the lung? In summary the following points have been established —

- 1.—The normal resting diffusing capacity is about 21 cc/min./mm. Hg for oxygen and about 17 for CO.

- 2—The diffusing capacity increases by about 75% on exercise and usually reaches its maximum well before the limit of effort or of oxygen uptake has been reached
- 3—The diffusing capacity is greater as one would expect in persons with a large lung volume
- 4—Increasing age reduces the diffusing capacity
- 5—There is evidence that the ratio between contained gas volume and the rate of diffusion is not constant within a normal lung
- 6—It has been realised that the measured overall rate of diffusion will be dependent on the ratio between ventilation and diffusion in different parts of the lung
- 7—Gross disturbances of gas diffusion have been demonstrated in disease sufficiently great to affect overall lung function

We come now to a major difficulty. In many respiratory diseases we know that there is a gross abnormality of gas distribution within the lungs and we may assume that there are in addition wide variations in gas diffusion in different parts. In cases where the lung has departed so widely from being an ideal single alveolus what meaning can be attached to an overall measurement of a single figure of gas diffusion? This problem is still far from solution and until this aspect of the measurement is better understood the interpretation of some of the results will remain a matter of opinion.

Figure 1 indicates some of the mechanisms which may be responsible for impaired overall gas diffusion. The examples quoted are intended to be illustrative and do not constitute a comprehensive list. It is clear that impaired diffusion as revealed by current techniques may be caused in a number of different ways and further that in a condition such as mitral stenosis—in which impaired overall diffusion may be demonstrated—alveolar wall change, inequality of gas distribution and inability to increase the cardiac output may all contribute to impaired gas transfer. The number of question marks on this figure illustrates the tentative nature of some of the conclusions that may be drawn.

Impairment of gas diffusion if of sufficient severity may show itself in a number of different ways—

- 1—By causing excessive ventilation for a given oxygen uptake the ventilation being required to keep the alveolar oxygen tension as high as possible
- 2—By causing arterial unsaturation on exercise the muscular weakness that follows may limit effort tolerance
- 3—If grossly reduced by limiting the maximum oxygen uptake to a very low figure. In

emphysema this may force the patient into the dilemma that the increased amount of oxygen that would be transferred if ventilation were increased is more than offset by the increased oxygen needed to achieve that ventilation.

Finally, how useful is this measurement in physiological study and clinical research? Physiologically, the method is of most value in giving information about the nature of the pulmonary capillary bed. In 1945 Irof Roughton in a remarkable and ingenious contribution used the kinetic equation for the rate of formation of COHb at different oxygen tensions to calculate the pulmonary capillary blood volume quantitatively. No one as yet has followed up this lead but there is every indication that the next few years will see a considerable advance in this aspect of respiratory physiology. It is also rather surprising that gas diffusion has not been more studied in experimental pulmonary oedema.

In clinical research and investigation one may single out three examples to illustrate the value of this type of study.

- 1—In pulmonary emphysema the overall diffusing capacity gives an indication of the state of the lung parenchyma. This information is not obtained from any of the ventilatory tests and it constitutes an essential part in the assessment of any patient who might have some degree of emphysema. The discrimination achieved by the measured diffusing capacity on exercise when young normal subjects are compared to cases of emphysema is shown in Fig. 2. Ventilatory tests of course show similar differences but there is good evidence that the two groups of tests are concerned with quite different aspects of function change.
  - 2—It is of particular use in the study of the occasional cases of obscure pulmonary infiltration that are met with in which the impairment of gas diffusion will forecast the alveolar wall changes that the pathologist will demonstrate and that the radiologist may have difficulty in showing.
  - 3—It may be used in the study of cardio-pulmonary phenomena such as left ventricular failure with pulmonary congestion. This condition may produce impaired gas transfer and changes in pulmonary diffusing capacity may be sensitive indicators of change.
- I hope this bird's eye view of an active field of respiratory physiology will serve as a basis for discussion.

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Figure 1

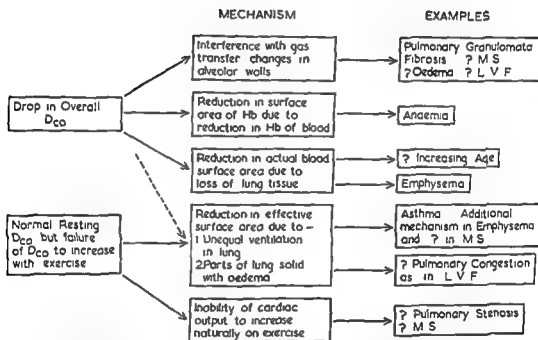
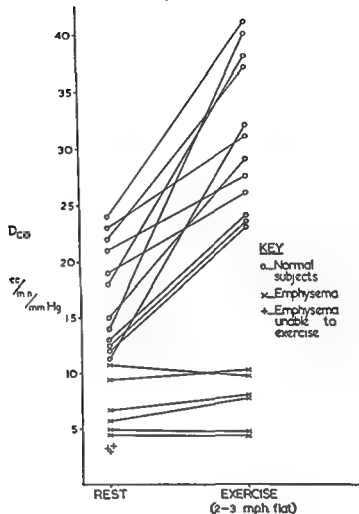


Diagram of some of the mechanisms of production of impaired overall gas diffusion Abbreviations—Dco=CO Diffusing capacity M S=Myocardial stenosis L V F=Left ventricular failure

Figure 2



Comparison between the diffusing capacity of normal subject and patient with emphysema at rest and on mild exercise. The range of the normal subject was 18 to 41 l/g or improvement in emphysema is principally caused by the destruction of lung parenchyma present in the condition.

# Breathing Machines And Assisted Respiration

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The development of mechanical breathing apparatus has greatly expanded therapeutic application of assisted or artificial respiration. As long as manual methods alone were available artificial respiration was only used in the treatment of emergencies such as drowning, anæsthetic failures or exposure to toxic gases where treatment was only required over minutes or hours. The introduction of the tank respirator by Drinker in 1929 opened the way to the development of mechanical methods suitable for chronic cases requiring respiratory assistance over weeks, months or even indefinitely. The potentialities of this form of treatment are in fact only just coming to be realised. Some of the conditions in which respirators have been used in addition to their use in acute emergencies are—

TABLE 1

**NEUROLOGICAL**—Polio-myelitis; Peripheral neuritis; Myasthenia gravis; Tetanus

**POISONING**—Barbiturates; Alcohol

**PULMONARY**—Emphysema; Acute respiratory infections in patients with grossly reduced lung capacity

**SURGICAL**—Thoracic surgery; Head injury

**PEDIATRIC**—Respiratory difficulty in newborn and premature infant

My purpose here is however not to discuss treatment of respiratory failure in these conditions but to describe the main types of respiratory or breathing machine and their uses.

A bewildering number of different machines has been designed but they fall into the following categories—

TABLE 2

**TOTAL VENTILATION**—Tank respirator (Drinker, Both, etc.); Positive pressure breathing machines; Volume cycled (Engstrom, Power, etc.); Pressure cycled (Aga, Pulmotor, etc.); Patient cycled (Bennett, etc.)

**PARTIAL VENTILATION**—Cuirasses; Rocking beds; Pressure belts

**TANK RESPIRATORS**—These are sometimes called negative pressure machines because they act by reducing the atmospheric pressure outside the body. Their effect however as far as the pressure differences across the lungs are concerned is the same as with so-called positive

pressure breathing. A tank respirator consists essentially of a coffin-like box with an aperture for the neck and a sponge rubber or plastic neck seal. The patient is ventilated by rhythmically lowering the tank pressure by 12–20 cms of water by means of a large bellows. Expiration is usually allowed to occur passively though in some respirators positive pressure can be applied to assist expiration. Modern developments in tank respirator design are mainly concerned with improving facilities for getting at the patient for nursing purposes and for ventilating the patient by positive pressure when the tank is opened or the patient removed from it as the case may be.

Some 900 tank respirators are available in this country and are distributed among fever hospitals and general hospitals. They form the reserve of mechanical respirators available for handling a poliomyelitis epidemic.

**POSITIVE PRESSURE BREATHING MACHINES**—These are classified according to the method of controlling the breathing cycle.

A volume cycled machine delivers a standard volume of air independently of pressure though it may be fitted with a blow-off valve to guard against dangerously high pressure being applied to the patient. Examples of this type of machine are the Beaver respirator made by the British Oxygen Company and the Swedish Engstrom respirator.

Volume-cycled machines are operated either by a piston pump in which case provision has to be made to prevent contamination of the inspired air with oil vapour or by a bellows. The form of the pressure curve is determined by the shape of the cam which operates the bellows or cylinder.

The stroke volume and frequency are adjustable and in the more complicated machines like the Engstrom respirator the wave form can also be adjusted. In Denmark and Sweden where large scale epidemics of poliomyelitis have occurred this type of apparatus is preferred for treating the more serious cases of respiratory insufficiency in poliomyelitis.

A pressure cycled machine pumps air into the patient until the pressure at a given point in the system (preferably near the mouth or trachea) rises to a set value whereupon a valve shuts off the air flow from the patient and the patient exhales passively to atmosphere. The best types of machine have magnetic valves in which the

cycling pressure overcomes the pull of a magnet. These are more reliable than those which depend on breaking electrical circuits by movement of fluid or mercury in response to pressure. In pressure-cycled machines a continuous gas flow can be used since the flow is merely diverted during expiration and not shut off. Cheap and compact machines are available using compressed air or oxygen or a vacuum cleaner blower.

This type of machine is very suitable for transport of acute poliomyelitis cases in ambulances or for other respiratory emergencies. It is also favoured by Scandinavian physicians for treatment of chronic poliomyelitis cases because it is relatively simple and cheap and the patients like it. It is contra-indicated in their view for acute cases.

1—Because if obstruction develops in the airway due to secretions etc. the machine can go on cycling without delivering its quota of air.

2—Because if a leak develops between the patient and the machine the machine may cease to cycle altogether.

**Patient Cycled Machines**—These machines tend to be more complex than other types because of the need to respond to small changes of pressure set up by the patient's natural respiratory effort. Some depend on mechanically switching others have electronic devices. They are used commonly in the treatment of respiratory embarrassment without muscular paralysis for example in emphysema particularly in association with atomisers for administering bronchodilator drugs. They have not yet found wide application in poliomyelitis.

Common to all positive pressure machines is the need for a gas-tight airway and since positive breathing masks can only be used over short periods their use over prolonged periods is limited to tracheotomy cases. In Denmark and Sweden it is common practice to keep tracheotomies open for months and sometimes years.

**Cuirass Respirators**—There have been many attempts to make cuirass respirators beginning as long ago as 1901. Even the most successful ones have not been efficient enough to keep severe cases of respiratory insufficiency alive and patients have died with pulmonary oedema from under-ventilation. By the 1930's models were available which were adequate for convalescent cases. One of the first was the I.C.C. Burstall jacket which was like a suit of armour encasing the whole of the trunk. Subsequent development particularly since the war have been towards greater ease of application combined with greater efficiency. Ease of application depends on having the minimum amount of

fixing behind the back. Respiratory efficiency depends on the amount of trunk included minimum restriction to rib movement both anteriorly and laterally and maximum diaphragmatic movement. The cuirass should seal behind the mid axillary line below the epigastrium (i.e. over the hypogastrium) and as high as possible on the sternum. The seals themselves should be very thick and soft to allow a certain amount of movement underneath. Such respirators belong to the chest-abdominal type as opposed to the less efficient chest type. Chest cuirasses tended to move the anterior part of the chest only. Chest-abdominal types aim at moving principally the diaphragm and lower ribs. The most recent one in this country is the Spira Shell developed by Dr Kinner Wilson and his colleagues and manufactured by the Medical Supply Association. It is claimed to give 25 per cent greater tidal volume for a given negative pressure than the well-known Monaghan type, the most recent model of which is also of the chest-abdominal type. The greater efficiency of the Spira Shell is due to the fact that it widens on suction whereas the Monaghan compresses laterally on suction.

Cuirasses are not suitable for acute cases for the following reasons—They may not give adequate ventilation, sealing is not completely reliable and posturing the patient for drainage is difficult.

**Rocking Beds**—These are now coming into use in this country having been used for some years in the U.S.A. Some patients prefer them to cuirasses and can sleep on them. They can be relied on to supply about 60 per cent of the total ventilation. Their main advantage is that the patient is completely unencumbered. The angle of tilt is usually 30–35 degrees (15 degrees head down and 15 degrees feet down).

**Pressure Belts**—These compress the chest during expiration. Inspiration takes place by elastic recoil or by the patient's own inspiratory effort. They are nowadays seldom used though they are good for convalescent patients who cannot keep to give the extra 100 cc of tidal volume.

**Electrophrenic Respirators (Sarnoff)**—These have little place in poliomyelitis. It is considered undesirable to stimulate affected muscle more over the nerve may eventually cease to conduct. It is also difficult to find the motor point and to keep the electrode on it. They may however be of value in patients with disordered action of the medullary centres who are difficult to treat in other respirators since they seem to inhibit the natural inspiratory effort.



Three important accessories used with breathing machines will now be considered

**Spirometers**—An important requirement in the practical use of any type of breathing machine is a spirometer since it is important to know the minute volume of ventilation and this cannot be determined accurately from the pressure changes. Some positive pressure breathing machines notably the Engstrom have a built in spirometer. Failing this a small gasmeter type spirometer is suitable.

**Suction Apparatus**—Some form of suction must be available for aspirating secretions from the respiratory tract. This can be done either by means of a separate aspirator pump or by a venturi tube incorporated in the breathing machine.

**Humidifiers**—In patients with tracheotomies it is important to prevent formation of crusts in the respiratory passages due to inhalation of dry air. It will be recalled that inspired air is normally saturated and at body temperature by the time it reaches the trachea. Many otherwise satisfactory breathing machines are deficient in this respect. Either they have no humidifier or the humidifier is too small to be effective or placed too far from the patient so that the inspired air cools by the time it reaches the patient and drops most of its moisture by condensation.

I should like to close with a few remarks on the treatment of respiratory poliomyelitis. Any one visiting Denmark and Sweden is likely to return firmly convinced that tank respirators are out of date and that a volume cycled positive pressure machine is necessary for adequately controlled treatment in severe cases of acute respiratory poliomyelitis and that a pressure cycled machine is the equipment of choice for the chronic case. This view is based on the Scandinavian experience that 70 per cent of

respiratory polio cases require tracheotomy at some stage and problems of nursing and medical care are much simplified by use of positive apparatus rather than with tank respirators. At Danish and Swedish centres tracheotomies are kept open for long periods in order to allow this method to be used.

In the U.S.A. on the other hand when comparable epidemics have occurred tank respirators are considered superior. The mortality at one centre which I visited was stated to be as low as 12 per cent compared with 25-30 per cent in Scandinavia. Tracheotomies are allowed to close early as soon as the patient recovers the power of swallowing. In the chronic phase wide use is made of rocking beds and curasses.

The difference between the two methods has grown up largely on the basis of the equipment which the different countries had available at the time when they began to have serious epidemics. Centres in the U.S.A. and Canada were already equipped with tank respirators. Denmark and Sweden had little equipment of any kind. They used manual positive pressure techniques in the emergency conditions of the early stages of their epidemics and later developed some very efficient types of positive pressure breathing apparatus.

In this country we are in the same position as the U.S.A. consequently it is unlikely that positive pressure breathing will be adopted on a wide scale for treatment of respiratory poliomyelitis. Positive pressure breathing has however a wide field of application in the other conditions listed above. It seems likely from a study of mortality rates both in Scandinavia and the U.S.A. that skilful clinical management backed by adequate laboratory facilities are more important in reducing mortality than the actual type of respirator.

## Augmented Respiration With Patient-Cycled Respirators

IAN DONALD (Department of Midwifery, University of Glasgow)

The need for an apparatus that would amplify respiratory efforts however feeble or irregular became obvious some years ago in the course of our experiments in treating respiratory difficulties in the newborn particularly premature infants. It had been found that an infant Drinker type of apparatus although

having a wide range of speeds of operation and pressures failed to produce any noticeable benefit because the baby fought the rhythm of the machine with its own spontaneous respiratory efforts if strong enough to do so and treatment along these lines more often than not hindered rather than helped it.

Respirators have therefore been developed which are operated by a servo-mechanism which is triggered by the onset of each inspiratory attempt. Such a respirator being patient cycled adjusts itself to the needs of the patient in so far as the respiratory centre is functionally competent and moreover the hypothetical possibility of hyperventilation is less likely.

Two main types of respirator have been used and are undergoing further development although both operate on the same triggering principle. In the first of these namely the servo-respirator the baby is enclosed in a miniature type of cabinet respirator in which negative pressures are applied to the body synchronously with the inspiratory phase. The neck and face are sealed from the body chamber by a setting solution of calcium alginate. In the other type namely the Pneumotron inspiration is assisted by intermittent positive pressure applied either by a face mask or by an endotracheal tube. This provides a short term emergency type of treatment in the hands of unskilled personnel. Positive pressures applied by a face mask with out regard to the timing of the child's respiratory efforts tend merely to drive the administered gases down the oesophagus into the stomach whereas if such a pressure synchronises with the natural inspiratory phase of the patient during diaphragmatic systole the pulmonary intake is more likely to be increased.

The triggering mechanism is controlled by a flap inspiratory valve which is mirrored. A light reflected from this mirrored surface on to a Germanium crystal is deflected at the beginning of each inspiratory phase and the output from the Germanium is sufficient to operate a sensitive relay. The relay controls two standard Elcontrol timing units the first of which provides the hold in time to determine the duration of the positive pressure. The second provides an automatic cycling time which causes the apparatus to work at any given frequency, if spontaneous respiration should cease and therefore fail to trigger the machine. Both circuits provide a wide range of settings. The output relays from these timing circuits are connected in parallel to a powerful solenoid which opens a piston valve. A positive pressure of approximately 4 lb. per square inch reduced in two stages from a standard gas cylinder is constantly applied to the piston valve. This system eliminates time lag between triggering and operation. Any gas mixture can be supplied and our preference is for a 50/50 oxygen and nitrogen mixture supplied from one cylinder.

The pressures delivered to the patient cannot exceed 30 to 35 cm. of water because of a water

operated blow-off valve. A regulator valve in the delivery system can adjust the rate of pressure rise within the mask.

In the event of apnoea the automatic timing circuit assumes control and continues to trigger the apparatus at any desired frequency until the next spontaneous inspiration triggers the next cycle of operation.

The efficacy of this principle of treatment is being studied by intracranial electromanometry along the lines of Dornhorst & Leathart (1952) and the pressure changes thus demonstrated within the thoracic cavity can be studied and compared with the pressures occurring in both natural breathing and other methods of artificial respiration. In the case of the servo-respirator the pressure effects of augmented respiration and spontaneous inspiratory effort have already been shown to be additive (Donald 1954). With the positive-pressure Pneumotron the pressure waves are of course reversed and the degree to which this reversal takes place gives some indication of the adequacy of the gas flow delivered by the apparatus.

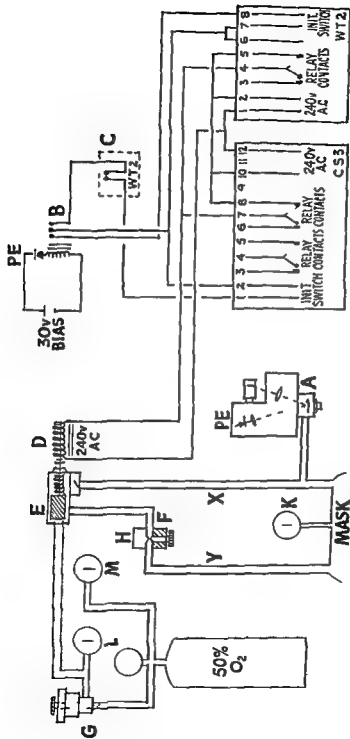
The Pneumotron has been designed also to provide augmented respiration in adults and experiments on curarized patients undergoing operation are being conducted and the effects studied by intracranial electromanometry. As spontaneous respiration returns the Germanium cell trigger takes over from the automatic timing circuit.

The apparatus has not so far been used in cases of respiratory paralysis complete or partial due to disease. Its value in such cases has not only to be established by objective measurements as above but has to be weighed against a certain degree of electronic complexity. Nevertheless the use of a Germanium crystal in place of the former gas filled photoelectric cell and D.C. amplifier together with standard timing units has already simplified the apparatus and made it more reliable than its prototype.

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A Inertial Mirror Flap Valve  
 B Germanium Junction Photo Electric Cell  
 C Trigger Relay  
 D Break Contacts to isolate CS 3  
 E Cycling Timer (Inspiratory)  
 F Cycling Timer (Automatic)  
 G 50% O<sub>2</sub> Gas Source  
 H Insulated Solenoid  
 I Piston Valve

F Volume Control Valve  
 G Pressure Reduct on Valve  
 H Blank off Valve  
 K Pressure Reduction Gauge  
 L Cylinder Pressure Gauge  
 M Exhaust Pressure Gauge  
 X Delivery Pressure Gauge

## DISCUSSION

Dr. C. M. FLETCHER

The great progress that we have made during the last 10 years in our understanding of lung function may be seen by comparison with a recent book such as that by Comroe and his colleagues (1955) with chapters on respiration in books of clinical physiology published 10 years ago. Despite this progress the various techniques developed for lung function studies are seldom used in clinical work in this country. Outside a few research units in which they have been and are being developed, it is fact a reflection on the lack of awareness or conversion of clinicians of the importance of the complete type of technique of the clinical work in clinical practice.

### Relevance of Lung Function Test to Clinical Practice

In the great majority of cases of the disease the clinician, endocrinologist and pathologist can proceed accurately to a diagnosis of the disease on the basis of the history, physical examination and treatment. It is securely based. Clinicians can only provide additional information on cases who have a disturbed function usually manifested by dysfunction or abnormality. Apart from the undoubted intellectual information provided by these tests, additional information is often provided by the use of the clinician or his patient.

In case with dyspnoea, suction is the most helpful  
two methods—

## (1) Measurement of the severity of dyspnoea

[illegible]

If we displace the vowels in the sentence "Normally, it is given to all of us, both as a rhythm and as a melody," we get "Normally, it is given to all of us, both as a rhythm and as a melody." This is a very simple example of a wordplay.

I both enation f sir n effort ar e  
 wh n the tivity sin rased (g guphill n walki g  
 n rea g entil on n breathing) or wh n th  
 cap city to p rfo m educ d (we kn s so stiffness  
 n walki g educ on n ventil tory cap city n  
 fre th g) An ind f dysp oea may th re so bly  
 be ba d pon m urem ts of th two f o  
 Th f t can be m urem ts of th ol m of air  
 be th d out by th p tent wh n he perform  
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 n the e ght In ord to allow f r or n t o  
 d c d ly p tite ts f h g to comp te the st nd d  
 p o d of e relie or fal g to hev r stady t

of exercise ventilation the total excess ventilation (above the resting level) is averaged over the actual duration of exercise. In other respects the lack of such standardization has led to confusion in interpretation of exercise ventilation and to dissatisfaction with the index.

The dyspnoea and x derived from this test (ver-  
cise entilation is a prop tion of maximum ventila-  
tion) correlates well on the average with clinical  
assessments of dyspnoea but there is a wide scatter  
of end e with e n e ch clinical group. This w d after  
m ht g t that th nd is a poor m but I  
believe that th att r due more to the inaccu cy  
of the subjective than of the objective and. In  
normal subject t has been shown that the inde-  
x on t nt from day to day so th t e n t cannot  
be used unreservedly for absolute measurements of  
dyspnoea t in be used confidently to assess the  
result of t t m nt on power on of dvers. Furth r  
more the test ro id a useful pointer to pn ble  
causes of the dyspnoea and a guide to th further  
investigation.

(b) Identification of the Cause of Dysfunction

The simple diagnosis test will show whether the diagnosis is due to a neurological disorder or to a functional disorder. It is likely to be possible to become a lawyer (see Table) and if necessary, further research into the test may be a good idea to identify the

In e with Hypoxaema th essent: l thing is to  
dscovr thm Apa t for th dff ulty of dist  
tng sh g p phrl from nt l y n s there ;  
th serous un l bilty l clinical se mnt of  
y no (Corroee and Bot lhn 1917) The clin n  
his no m e ; t f tion for th d gnosis and treat  
ment of hypo m a without labo lry guidan e  
th n h h a for th d gnosis and t eatm nt of  
m mply on th b a of p llo Mcasuram nt  
of t l lio d o y n tur tion vent al in the  
d gno s of t l v s of r p tory f l l u r n d m a  
ment of CO ten on v e nt l both in d gnosis  
nd m g m nt The l t i m urement p r  
t ula ly mpo nt nt n case rec n l ted re p a  
t on by th t h n q a wh h r v b n d r l ed to  
u so th CO t a n a t th mo t el th l t  
of und o o r v e t l t on

Compl. ty of Lung Function Tests

The technique of the test which I have learned  
 is not only more complicated than that  
 of W. R. Inman's test of many other clinical  
 pathologists. Indeed, I agree with the  
 help of the implication which the peak flow  
 meter and the manometer is a most delicate  
 by Wright (1955) should be with the accuracy of  
 any physician in the outpatient department is on  
 ultimate in the form of the most delicate tests a not  
 yet utilized for the most we must hope that  
 it will not be left behind they too have been  
 implied so that they can be done by those with uti-  
 lize training on the job.

My conclusion are that me in nt of l n  
f n l n e lly e s nt fo th p p r d g n s  
u d r s t d g e m n g m n t of m n y f n t l l  
c s s with f u c t o n l d s t u l a o f th l n g and  
th t at l e t t e m p l t t t r e w n th n s c o p e  
o f n y l n l d p r t m t t e m u t h o n t h

symposia such as this may help to draw attention to the need for wider use of modern techniques

Details may be obtained from Dr B M Wright Pneumonomiosis Research Unit Llandough Hospital Penarth Glamorgan

## TABLE

### Increased Ventilatory Demand

- 1—Line entilation or blood circulation (e.g. emphysema pneumonia collapse)
- Atrial capillary block (e.g. pulmonary oedema or granulomata)
- 3—Light to left hunt
- 4—Neurosis
- 5—Increased sensitivity of respiratory centre (e.g. altitude)

### Decreased Ventilatory Capacity

- 1—Loss of functioning lung (e.g. emphysema collapse reaction pneumothorax)
- Pulmonary congestion (e.g. heart failure)
- 3—Pulmonary fibrosis
- 4—Airway obstruction by primary and secondary
- 5—Emphysema
- 6—Mucular disease (e.g. pharyngitis)
- 7—Rigidity of thoracic cage (e.g. ankylosing spondylitis)

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## Dr ROBERT COOPE

It was said of a certain report that it reflects the attitude of a man who clammers the whole course of thought by first asking the two fundamental but so often neglected questions

What do we know about this

What do we need to do about this

You have thought both these questions thoroughly in the symposium and so you have invited both the wise and the prudent—the scientist to discern the things and the doctor who (once convinced that they are true) is killed to apply them—or some time prudent not to apply them

The working physician is likely to be out of his depth when confronted with some of the moreoteric equations of the respiratory physiologist. Nevertheless we must measure things and analyse them as accurately as we can and therefore equations there must be. I myself have a particular affection for this one

### Impedance Equation

(after Coffin and Wainwright) *Physiol Physicochem Biol u Pharmacodyn Path u Med u so Wester* 1900 3004 96)

$$RHPNI = \frac{\mu I + hS\pi - (PBRB + nr + ck)}{\beta \Delta}$$

Where RHPNI is the resistance of the humdrum physician to new ideas  
 $\mu I$  is mental inertia  
 $hS$  honest scepticism  
 $\pi$  thou hfulness for the patient  
 $PBRB$  partial pressure of the backroom boys  
 $nr$  nece sarv receptivity  
 $ck$  cerebral compliance  
 $\Delta$  the atmosphere of Bonnie Dundee

What does the working clinician get out of all this present activity?

1—The excitement of knowing that intensive work is being done in the respiratory field after a long gap when scientists appear not to have found any great enjoyment in tackling its problems. The working doctor always has a sneaking hope that something may be produced from the conjuror's hat to make his job of delicate judgment easier and that there will emerge facts and figures which will be really more helpful to him than what are called clinical impressions

2—An appreciable though as yet limited practical illumination with the promise of more—for example the mechanism of  $CO_2$  narcosis is the light thrown on suboxygation on the result of uneven ventilation and so on. It is true that sometimes things are being measured in detail which to the clinician are obvious in a rough but adequate way. Moreover there is the occasional clinical problem which only research techniques can solve

3—The promise of a much clearer conception of the cardinal processes though speaking for myself mathematic thought will somehow have to be translated into pictures (rather as Comroe and his co-workers try to do in their recent monograph). In this Symposium I certainly sense a strenuous outpouring of energy both from scientists and doctors in the attempt to clear our way through the forest of facts which are now being accumulated. We are all striving towards a better integrated view of our own field. I would hazard a bet that this is eventually going to lead someone like Professor Arnott (for example) to link up with a Sydney Coulson's department of mathematics at Oxford to produce an electronic computer which will iron out all the variables and put them in their place and as a spectator I am all for it!

The physician's integration however has to be rather different for his most important and persistent variable is the ill person of whom he has to take care. Moreover the art is long time is fleeting and life is short. So inevitably the working doctor must ask questions (of himself and others) such as these—

Do your figures interest me as they are really help me to manage this sick person? Does this technique or that give us clinical results commensurate with the time (and money) spent on them in other words do they really pay their way in the sphere of clinical medicine or surgery or are they for the research laboratory and the occasional problem? Are they worth on balance any pain or stress or inconvenience which they may bring on to our patient?

There is thus the curious situation that while the working doctor wants as much help as he can get from the scientist yet at the same time he is apt to prefer the Greek bearing gifts and the suzerainty of the shaman to the journey really

need say? It sound churlish but in fact it is not really so and whenever you fall ill yourself you will understand. Moreover once you have conceded that the journey is necessary you will get his full support and he can usually carry the dry with the patient.

4.—It would be a good idea if some respiratory tests were rechristened respiratory tricks. That would remind you of their intention their scope and their limitations. I would give maximal breathing capacity as an example.

As an older physician I have been fascinated to look back over the years and realise that while we taught (for example) vital capacity partly because we thought physiology the basis of medicine and partly because we did not know any better in actual fact we did not rely overmuch on it. I fear that we had one thing and did another. Instinctively, we relied on something more dynamic: we tested by load, asked what the patient could actually do in running, or walking, or straining, up or on two flights of stairs. We also asked what he fit to do the trick? And furthermore was he doing his best? And yet again, I don't know why not? Then as now the co-operation of the patient was recognised as a crucial factor.

5.—If we could live with a patient for a long time and observe him continuously and so by we should have a better idea of how he stood. There is a good deal of mere lip service given to the idea of clinical history yet an experienced doctor can often elicit a history from the patient which is a good equivalent of a written history. In the case of the up and down of the line to emerge vividly. These are facts which may well be very important to the doctor's act of judgment, than any figures provided by the respiratory physiologist. I will give you a very simple illustration.

The patient known for some years to have mitral stenosis was sent to hospital for possible operation. The only contraindication of any note was an attack of influenza a few years before. There were no present symptoms of influenza, both X-ray and with the assistance of clinical pulmonary hypertension whatever it seemed that operation was hardly justifiable. However, the patient experienced pleurisy of his chest. I noted the fact that over the previous 12 months he had been troubled by small amounts of blood (which had been described as episodes of iron mucus) of no account. And the attack of influenza came gradually on analysis as almost certainly a first breakdown to congestive cardiac failure from which she did not recover for about four months. At operation a surprisingly tight stenosis was found.

6.—Often the doctor cannot follow the scientific ideal because of the emergency of the problem. For example, every ill person in the country can produce one or two old girls with chronic bronchitis, emphysema and suboxynation who are slowly deteriorating with white. It would doubtless be good to know just how much suboxynation they are enduring but it is clearly impossible to do arterial puncture on them all. Does it matter anyway? When does it matter? How far can the clinician stay his finger? I don't know. But still, I believe, best be done. Can the clinician do it in these techniques so he can open his purely clinical judgment that he can eventually discard the techniques.

7.—It has always been true that the future of medicine depends greatly on the progress of physiology and metabolism and contemporary diseases.

coveries in the basic disciplines of physiology, biochemistry, pathology and the rest. If I were a benevolent dictator I would demand the young man who wishes to become a practising physician in a teaching hospital should have spent a year or two in one of these basic departments—in my view after he has learned clinical nous in the wards. If he wishes to take a special interest in respiratory disease, he ought moreover to work in the relevant scientific discipline including the carrying out of special techniques and the exercising of his mind on the problems involved. Later when he is a physician he will eventually become too busy to do them himself but his laboratory work will always remain a background and he will be at home in the field. He will be able to use it as a basis for self-criticism to check the accuracy of his clinical observation. He will almost certainly come to know better than the scientist how applicable laboratory tests are to his clinical task. Indeed it is he and he is the only who can integrate the clinical and laboratory disciplines and be able to answer the practical question which I have indicated earlier.

I have intended earlier but forgot to reiterate a protest against the respiratory physiologist's use of the term fibres—when he calls it physiology fibres is indicating that it is not necessarily fibres at all in the long accepted pathological sense. Young ladies on occasion are allowed to say "No, when they mean yes" but not physiologists surely?

# Professor D SILVA

One aspect of the measurement of respiratory function concerns the assessment of the mechanical function of the lung. There is a number of objects to the determination of the maximum breathing capacity such as (a) the need for full co-operation by the patient whilst performing a difficult respiratory manoeuvre of which he has usually had no previous experience (b) the variations which have been described in the method of performing the test and (c) perhaps the inadvisability on clinical grounds of leaving a patient to undertake the unsatisfactory manoeuvre of expiration against the test.

We have found that by combining measurement on both the fast expiratory and the fast inspiratory vital capacity curves it is possible to forecast accurately the maximum respiratory capacity of normal subjects.

Two points are noteworthy: the fast expiratory and inspiratory curves are different in shape and duration, maximum breathing limit of inspiration is little below the maximum respiratory level. The fast expiratory curve is very close to an exponential curve where the maximum portion of the fast inspiratory curve is very close to a straight line. The curves are a good fit to the respiratory and inspiratory portion of the tracing of maximum breathing. In other words, a tracing of maximum breathing can be regarded as made up of portions of fast expiratory and fast inspiratory curves. Hence by assuming the limit of inspiration to be at different levels of full inspiration and knowing the duration of one complete respiratory cycle it is possible to plot a family of curves which will indicate the relationship between the respiratory rate and tidal volume expressed as a percentage of the vital capacity at any assumed level of inspiration. These curves show that the optimum limit of inspiration

tion varies slightly with the rate of breathing. From this data the maximum ventilatory capacity (MVC) at any known rate of breathing can be calculated.

A comparison between the MVC calculated from these theoretical considerations correlates very highly with the MVC directly measured for a group of six normal medical students.

Our experiments on abnormal subjects are not yet complete but it seems probable that it will be possible to forecast the MVC by making appropriate measurement on the first expiratory and inspiratory wave alone.

## Dr W A BRISCOE

I find myself in agreement with Dr Cooper's very wise remarks and have at times had doubts as to the clinical usefulness of studies of the mechanism of the lung. On such occasions one should remember that the acquisition of useful but interesting new knowledge is its own justification. In this case we were applying tourniquets for haemorrhage before Harvey's discovery of the circulation and his discovery might thus have been regarded as useful by the physician of his time.

I find that I did not explain sufficiently clearly why blood taken from a wedged catheter is not a sample of blood in the pulmonary artery. As soon as you withdraw the catheter the blood flows through a group of alveolar capillaries and the continuation of ventilation ultimately in the capillaries containing a high proportion of inspired air in composition. When pulmonary venous blood is withdrawn into the catheter it must lose carbon dioxide and take up some oxygen as the result of its exposure to inspired air in these alveoli. There is a dense area of the low CO<sub>2</sub> lines of such samples in the Scandinavian literature. If this is not realised, wedged catheter samples may be interpreted as representative of pulmonary venous blood.

We have heard a lot about diffusion. I should now like to say a few words about uneven ventilation, perfusion ratios and the very large contribution they make to the alveolar-arterial oxygen gradient of both normal and emphysematous subjects at rest breathing.

Eighteen minute studies were done on six normal subjects in Dr Cournaud's department and interpreted by new techniques. The alveolar-arterial oxygen gradient expected from the mixing studies if the lungs were evenly perfused with blood at 10 mm Hg with a standard deviation of 1 mm Hg, the component due to uneven ventilation-perfusion ratios is only part of the total gradient about 1 mm Hg must be added for the shunt of blood past the alveoli and 1 mm Hg or less for the diffusion gradient. The total of the three components is thus about 13 mm Hg. However, the observed total gradient in normal subjects is only about 10 mm with a standard deviation of about 5 mm. It appears that our estimate of the component due to uneven ventilation-perfusion ratios may be slightly too great. It was calculated on the assumption that the lungs are evenly perfused with blood. There are only two possible ways in which this component could be smaller either our data are wrong or else there is under-perfusion of the less well-ventilated alveoli in the normal lung. In either case the component due to uneven ventilation-perfusion ratios is far the bigger component in the alveolar-arterial oxygen gradient of the normal resting subject breathing.

In studies on emphysematous subjects in Dr Cournaud's department the same general conclusions hold. Uneven ventilation-perfusion ratios account for a very large part of the total alveolar-arterial oxygen gradient so much so that it may be necessary to make under-perfusion of poorly ventilated alveoli to explain the data.

## Dr A BRIAN TAYLOR

During the last five years my colleague Dr Armitage working in Professor Melville Arnott's Department and I have used a non-spirometric technique for differential study of the two lung aparts from the general information obtained it has been of particular use before operations such as pneumectomy to assess the competence of the remaining lung to support adequate respiration and also in cases of lung cyst and so on to indicate the need for surgical treatment to increase the function of the affected side. It has been a simple procedure. At the end of routine bronchoscopy and local anaesthesia a sample of expired air is withdrawn simultaneously by thin tubes from each main bronchus and from two levels in the trachea. These are analysed for oxygen and carbon dioxide content and the respiratory quotient obtained. Analysis of the relationship of the respiratory quotient of each lung to that of the tracheal samples indicates the relative contribution each lung is making to total respiration.

A number of cases have now been estimated in this way. Clinical estimation has supported the findings and post-operative results have conformed with expectation. One case of total bronchiectasis in one lung was found to have 19% of the total respiration coming from the affected side and resection seemed too hazardous. This was confirmed as after instilling on operation the patient's post-operative course was stormy and subsequent small respiratory infection led to fatal result.

## Dr HUGH JONES

Dr Hugh Jones emphasised the value of using the dyspnoea index (ratio of the ventilation required at a known rate of exercise to the maximum ventilation) as a criterion test for lung function studies. As Dr Fletcher pointed out if the standard deviation of ventilation (SV<sub>v</sub>) were used as the measure of ventilation cost of work then it did not matter whether the steady state was achieved or not within limit, however the subject was able to exercise provided the work was done at a rate for which the normal standard deviation was known. With the step test method (1) and D.W. height and anemometer the apparatus as now very simple and with the same equipment the maximum voluntary ventilation (MVV) could be done as the measure of maximum ventilation. The cheap disposable polythene bags readily available commercially would probably easily overcome any apnoea and the problem of sterilisation. Dr Hugh Jones agreed with Dr Donald that the step test is a better performance test than the dyspnoea index derived from it related to the dyspnoea for any other particular exercise day to day for which a specific test would be needed. The individual values of the SV<sub>v</sub> and MVV measured as Dr Fletcher described were each needed

as p l min = s to t sts of lun<sub>h</sub> function one re on  
for luting the one to the other was in assessing for  
e ampl chan in d<sub>h</sub> j n x a and th mechn smry of  
th t change a the result of lurg, or h art smry of  
In this respect Dr Hugh Jones agree 1 sth Dr Coog  
r marks bout th alue of cln cal judgment luf t l t  
that if a ign or symptom could be me ured then  
me rement was better than judgment He had great  
sympathy with those who felt that more and more  
l function tests were being produced but sd that  
t wa no ex d nt th t cert in group of t sts were  
useful for rout ne assessment and he showed slides  
of the pro f rmas for those to be ued at the London  
Poster duate M d c l School H mme mth Ho pital

On d difficulty with lun<sub>h</sub> funct on t ts was th t th  
r gers of norm l alues e e depend nt on the par  
cular patient s a e s e body position t the t me of  
th t test and so on Apa l f om the nple d<sub>h</sub> p n  
nle the lun volume were often d n in a clod  
ci cut apparatu as routin s me surements Th  
remand r of the tests fell into two groups The first  
p helped u th analysis of a lowered vent latory  
capac ty and on listed of s mple timed vital capacity  
d m ximum expiratory flow t sts or the slghtly  
m complex analysis of the work of breathing u in  
methods de loped by M d and Wittenberger (2)  
Th second gro p analysed e e ease vent lation and  
clud d blood gas t ms ons indices of ent latory  
ineq lity (3) now much s mplified as Ham msmith  
by uing th uique mass spect ometer des gn d by  
M h Fowl r and finally ca bon monoxid uptake f r  
me suring gas trans f r to the blood

At H mmer Smith they w re at rtin<sub>h</sub> regional gas  
sampling w thn the lungs using the mrs spectro  
meter wh h as Dr Brian Taylor h d mentioned from  
work at Birmingham might well uper eed broncho  
p om try and cert nly g = l d d in g l t nio lung  
function

Dr H gh Jones fin hed by m kng two omment  
o the th ctical p t of l ng fuction test  
Ad ece c tic sm of some tests as in cc r te and  
poorly rep table co ld b m placed the mpor  
t nt d for a t at was its disc mination n mely  
s repeat b lity elated to the ran e of chnge t  
sh w d f m n mal to go ly abnormal subjects  
Th s t l e pac ty was more repe table but l d s  
er min ting th the m ximum volunt y nt lation  
A u ful an l gy was w th the measurement of length  
if a long d stance r ther than a short o e w to b  
m a red t n a le with co rse d ons (analo ou  
to test r peatablity) m ht then be at f c t ry  
I a tly t w often sal tory to reflect wh th r tests  
m as ed what o e th ght they d d and he deser bed  
facto analysis s a statistical p ocedu so find  
g to what e tent on te t measured the same thing  
as an ther (3)

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## Dr McKERROW

In the me u em us of vent latory capacity on  
frt juently fi d that th ma ximum breathing capacity

t t takes s ther too much time or = ces tate too  
much co-operation from th subj ct We have found  
th s to be particularly true in some field survey work  
in wh h we have attempted to collect information  
on the ventilatory capacity of la ge group of subjects  
In these cases we have used the timed tal capacity  
(TVC) which as Prof sor D Silva has sad has  
ce tain theoretical dsad ntages and yet we feel it  
to be suffic iently accu ate for our purpose

It can be seen on the slides that the relationsh p  
between the M V V or M H C and the timed vital  
capacity is quite a satisfactory one in the field  
observat on studies The correl tion between the two  
ts is about 0.8 which s ugests that at any rate  
they r me suring the same physiological function  
although such a correlation = not h gh enou h to  
nbl one to pred = the actual results of on test  
from the other Th rem tning two slides illu trise  
th rept b lity of the te t hen done in the sam  
group of people on two different days and also when  
done on d fferent oc as ons by two d fferent observer  
Ag in t can be seen that the agreem nt in both  
re s satisfactory

## Dr PAYNE

I ould lik to mention the us of Prof sor  
Don lds Key r tor in the c e of an elderly wom n  
who d eloped re p tory fa lure following bil t ral  
adren lectomy As resp r tory failu was complete  
t w felt that some form of patient triggr d  
mech nsm would be most suit ble to asst her  
resp tation She therefore onected to the  
lneum t on and adequate nt lation m nt ned by  
th me n for a pe od of thrty hours

In th ca e th Pn um tron certainly pro d ts  
worth but the are I think three mpro ements  
which ould u fully b m de—

- 1—A qu eter me h n m would be bnou to botl  
r t nts and staff I und rat nd f m Prof sor Don lds  
th t this s fact s being provid d
- 2—Fo p lon ed = some type of humid f r  
ntial
- 3—An nd c tion of the olume of gas be ng  
l lvered per bre th wou d b valu ble

## Dr A B KINNIE WILSON

Patients with re p i om yelit oft n h e vry  
unst bl cardio scular y t ms R sons so a sudd n  
fall n blood pressure mgt t incl de —

- 1—P t l destru tion of th somotor e nt ly  
th d p oced Eng t on has hown that th s m v  
b mpatible w th dry lu gs and no mal blood  
g es in e e re p tory ca
- Interferenc w th n p at on by trache l ction  
Th n p ed r s w thdrawn b ck into the sucke  
before it catches th al role using = precipito f ll  
in rt nal oxyg nation
- 3—Postur l drana e m n eou rra which cause a  
udden n re e n the numb r of blocked bronchi a  
postu cl g d
- 4—Over p d r mo al of accumulated CO a  
when the ara v s sudd nly cl ared and the vent l  
tion p urc not reduc d Th m v cause a pre  
cipito is fall of the previo sly in re sed blo d pres u  
Th st te s p r tcula ly d ffcult to de l with



Dr C M Ogilvie said that the interpretation of values obtained for diffusing capacity and the clinical application of this measurement must depend upon the establishment of a normal range. The wide variations in normal values reported in the literature are due in part to differences of technique but it is apparent that there are also real differences among individual normal subjects. In Dr Comroe's laboratory in Philadelphia the single breath test gave reproducible values for diffusing capacity (for CO) in the same subject but resting values ranging from 11 to 40 ml/mm/min were obtained in a group of healthy male and female subjects of varied age and size. It was found however that there is a definite correlation between diffusing capacity and body size (which is presumably related to the size of the diffusing surface of the lung) and that normal values for women are lower than those for men. No significant difference was noted between the values obtained at rest in the young and old age groups. Cohn et al (1954) have reported that the maximal diffusing capacity (for oxygen) on exercise progressively decreases with age. The maximal value does take into account the whole area of pulmonary capillaries bed available for gas exchange. Resting values should be sensitive to a diffuse change in capillary permeability but might not reflect a small reduction in total capillaries since the whole of this is not required to function at rest. A low maximal diffusing capacity with a normal value at rest in older subjects may therefore indicate a reduction in the number of capillaries available for gas exchange rather than an alteration in their permeability. This could be due to the obliteration of larger vessels and

does not necessarily point to any degenerative or other primary process in the capillaries themselves.

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## Dr K W DONALD

Dr K W Donald stated that he could not entirely agree with Dr Bates that anaemia of itself would cause reduction of the diffusing capacity of the lung. In a normal resting person breathing air only 2% of the haemoglobin arriving in the alveolus was reduced and available for oxygenation whereas in a person exercising violently there would be three times as much reduced haemoglobin available in the same quantity of blood. It would not be suggested that the diffusing capacity was raised because of this. Further, in cases of anaemia there was usually a considerable increase of blood flow in unit time through the alveolar capillaries. The avidity of the blood for gas being increased certainly affected the quantities crossing the membrane but it was the diffusional properties of the membrane that were being studied which then expressed as a quantity of gas transferred/gas tension gradient ratio would not be affected by such considerations. Dr Donald endorsed Dr Bates' remarks concerning the value of exercise studies on patients complaining of symptoms during exercise. Even if no measurements were obtained one had far more insight into their exercise tolerance. Many patients were through no fault of their own very unreliable witnesses about their disability on exercise.





